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นางสาวนัยนา นัยโมลี

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

SURFACE AND SUBSURFACE WATER CONTAMINATION BY LEACHATE FROM DISPOSAL SITE AT TAMBON KHLONG KWANG, AMPHOE SAINOI, CHANGWAT NONTHABURI

Miss Naiyana Naimolee

สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

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By	Miss Naiyana Naimolee
Field of Study	Geology
Thesis Advisor	Assistant Professor Nopadon Muangnoicharoen, Ph.D.
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Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master 's Degree

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พื้นที่ทิ้งขยะของจังหวัดนนทบุรี ตั้งอยู่ที่อำเภอไทรน้อย จังหวัดนนทบุรี ครอบคลุมพื้นที่ 108,800 ตารางเมตร พื้นที่สำหรับทิ้งขยะประมาณ 73,600 ตารางเมตร พื้นที่ทิ้งขยะเริ่มใช้งานตั้งแต่ปี พ.ศ. 2525 จนถึงปัจจุบัน วิธีกำจัดขยะโดยวิธีฝังลงใบบ่อยืมดินจนปัจจุบันเต็มจึงกองสูงขึ้นมาจากพื้นดินประมาณ 10 เมตร โดยปราศจากสิ่งปกคลุมตัวขยะ ปริมาณขยะที่อยู่ในบ่อดินประมาณ 360,657 ลูกบาศก์เมตร อยู่บนพื้นดินประมาณ 800,000 ลูกบาศก์เมตร จากการเก็บข้อมูลเป็นระยะเวลา 1 ปี ภายในรัศมี 2 กิโลเมตรโดยรอบพื้นที่ทิ้งขยะ โดยเก็บตัวอย่างน้ำผิวดินจำนวน 7 แหล่ง จากบ่อน้ำระดับตื้น 4 บ่อ เป็นบ่อสังเกตุการณ์ภายในพื้นที่ทิ้งขยะ 3 บ่อ บ่อของชาวบ้าน 1 บ่อ และ ทำการเก็บตัวอย่างน้ำจากบ่อบาดาลในระดับลึก 9 บ่อความลึกของบ่อ 200 - 250 เมตร ตัวอย่างน้ำทั้งหมดนำมาวิเคราะห์ทางเคมีเพื่อศึกษาการปนเปื้อนของน้ำผิวดินและน้ำใต้ดินโดยน้ำชะขยะมูลฝอย ผลการศึกษาคุณภาพน้ำบ่งชี้ว่ามีการปนเปื้อนเฉพาะในบ่อบาดาลระดับตื้นที่อยู่ภายในพื้นที่ทิ้งขยะ ส่วนน้ำผิวดิน น้ำใต้ดินที่ระดับลึกไม่มีการปนเปื้อน แต่ในอนาคตอาจมีการปนเปื้อนได้ ถ้าขาดการป้องกันที่ดี

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ภาควิชา.................ธรณีวิทยา............... ลายมือชื่อนิสิต...
สาขาวิชา................ธรณีวิทยา.............. ลายมือชื่ออาจารย์ที่ปรึกษา.......................................
ปีการศึกษา…………...2545…………… ลายมือชื่ออาจารย์ที่ปรึกษาร่วม……………………….

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KEY WORD: SURFACE AND SUBSURFACE WATER CONTAMINATION / LEACHATE / DISPOSAL SITE / NONTHABURI

NAIYANA NAIMOLEE : SURFACE AND SUBSURFACE WATER CONTAMINATION BY LEACHATE FROM DISPOSAL SITE AT TAMBON KHLONG KWANG, AMPHOE SAINOI, CHANGWAT NONTHABURI. (การปนเปื้อนของน้ำผิวดินและน้ำใต้ดินโดยน้ำชะขยะมูลฝอย บริเวณพื้นที่กำจัดขยะมูลฝอย ตำบลคลองขวาง อำเภอไทรน้อย จังหวัดนนทบุรี) THESIS ADVISOR : ASST. PROF. NOPADON MUANGNOICHAROEN, Ph.D., THESIS COADVISOR : MALATEE TAIYAQUPT, [PAGES] pp. ISBN 974-173-321-6.

A provincial solid waste disposal site at Amphoe Sainoi, Changwat Nonthaburi was studied. The disposal site covers an area of 108,800 m^2, as 73,600 m^2 of dump waste, and has been in service since 1982. As a general practice, the wastes are openly dumped and left uncovered for the natural decomposition. In the earlier period, the wastes were dumped into an excavated pit, then piled up higher above the ground level. The sub-ground waste volume is 370,657 m^3, and over 800,000 m^3 above the ground. Water samples in the adjacent areas with a radius of 2 kilometers from the site were collected for a period of 12 months. Seven water samples from surface locations, four from shallow monitoring wells, and six from the 200-250 m. deep wells, were chemically analyzed to detect the potential contamination due to the leachate from the disposal site. The water quality analysis suggested that the shallow subsurface water resource within the site be contaminated while the surface, deep subsurface, and some distant shallow subsurface water resources are not yet contaminated at the present, but could be in the future.

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Department…………..Geology…………..Student's signature..

Field of study.........….Geology…………..Advisor's signature..

Academic year ……….2002…………….Co-advisor's signature..

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CHAPTER I

INTRODUCTION

The problem of solid waste management in Thailand is one of the significant environmental concerns. This results from the population growth and rapid economic expansion, lack of good areal zoning, inadequate basic public utilities, and inability to control the disposal of municipal and industrial wastes with the significant increase of solid waste quantity.

Though the environmental problems have already been recognized, there are still insufficient basic knowledge and study, both in the field of engineering practice and natural environment. The discarded and uncollected municipal solid wastes in the public places are mixed with the hazardous wastes and dumped onto the disposal site. The unsanitary waste disposal practice is apparently an obvious example of such problems.

Furthermore, the relevant governmental agencies could not collect all disposable solid wastes every day due to the inadequate collection equipments, personnel, and lack of cooperation from the public in keeping the community clean. Thus the uncollected wastes are left strewing everywhere. Moreover, the usual way to dispose solid wastes by the municipalities and local governmental offices has not been in accordance with satisfied efficient and sanitary practices.

Most municipalities in the country still employ the improper waste disposal methods by simply dumping all wastes into excavated pits or piling them on the ground for natural decomposition without soil covering nor burning. By this way, the solid wastes create the problematic pollution which threaten the public health by producing unpleasant odor, being the source of houseflies, distributing disease germs, and generating leachate containing various pollutants and toxic substances, especially heavy metals, which would migrate and find their way to contaminate the adjacent surface water or permeate down through the soil layers into the groundwater which is the significant water resource used for the public consumption. Also, the agricultural farmlands near the solid waste dumping areas are affected. Consequently, the farm productivity declines. Unless the contamination investigation, coupling with the accurate assessment and the ultimate remediation plan concerning the leachate contamination to the natural water resources are implemented in time, it is anticipated that the degree of environmental impact in the long term will be aggravated and the problem will be so complicated that the cost of disposal site remediation is substantially high.

The investigation needs a multidisciplinary knowledge in particularly geology, hydrogeology, soil engineering, applied chemistry and environmental sciences. In order to obtain both the quantitative and qualitative information, a general knowledge of the geology and hydrogeology of the disposal site will be much important.

Moreover the most effective waste disposal management strategy is to take an advantage of the natural hydrogeological characteristics and attenuation properties of the subsurface. This strategy is likely to guarantee a great protection of groundwater in the long term (Allen, 2001).

1.1 Objective and Scope of the Study

The objective of this present work is to study the potential contamination of the surface and subsurface water due to leachate from a specific disposal site. This could be done by studying the chemical properties of water samples collected within 2-km radius around the disposal site. The water samples were collected from 7 surface localities, 4 shallow water wells, 3 of which are the monitoring wells around the dump site, and 9 deep water wells. The sample collection was done 5 times during August 2001 till June 2002.

1.2 Previous Works

Ramnarong (1973) studied an artificial recharge by injecting clean flood water into an underground reservoir. The main purpose of that project was to study the possibility of discharging flood water in Bangkok into an underground aquifer, and consequently study the aquifer characteristics. The study was located at the Thai-Germain Agricultural Training Center, Bangpoon, Changwat Pathumthani.

Piancharoen and Chuamthaisong (1976) suggested from the data of groundwater wells in Bangkok Metropolitan that the thick sequences of unconsolidated and semi-consolidated sediments overlie the basement complex in the Chao Phraya Basin. These sediments are varied in age from Tertiary to

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Quaternary. They could be divided into three major episodes of deposition. The first episode was the Cenozoic sediments overlying the basement complex that appeared at the depth of 400 meters. The lowest most formation comprises of well sorted, medium to coarse sand with occasional gravel appear at the depth of 100 to 400 meters. The second layer appeared at 250 meters depth in the northern part of Bangkok and gradually getting deeper to 400 meter depth in the Gulf of Thailand. The third incident was found from 100 meters up. The upper most formation is dark gray to black marine clay, soft to stiff, and 20-30 meters thick.

Piyasena (1979) proposed that the subsurface geology of Bangkok comprised three sand layers alternated with clay layers. He proposed the lithologic analysis of groundwater wells in Bangkok area by systematic correlation procedure and delineated the stratigraphy of Bangkok subsoil.

Japan International Cooperation Agency (JICA) (1995) published the final report of the study on the groundwater management and land subsidence in Bangkok Metropolitan area and its vicinity. They analyzed the data from the monitoring wells of the Department of Mineral Resources. The study showed that the groundwater level in study area was lowering because of the effect of the regional declination of groundwater level due to the overpumping in the vicinity area.

Consultant of Technology Co., Ltd. (1998) was selected by Nonthaburi Provincial Administration Office to study and design for detailed improvement in closing the old disposal site while designing a new disposal site in accordance with the natural environment of the disposal site and investigating for a proper engineering practice and hydrogeologic condition of area.

Pollution Control Department (1998) studied the disposal sites at the northern region of Thailand, from 25 municipalities in 17 provinces and at the central region from 29 municipalities in 11 provinces. The scope of study was to collect the data of disposal site and surrounding environment. After then Changwat Nonthaburi is one of 15 disposal sites being selected for installation of monitoring wells to collect water samples for quality analysis.

CHAPTER II

PHYSIOGRAPHY AND HYDROGEOLOGY OF CHANGWAT NONTHABURI

2.1 Physiography

Changwat Nonthaburi is situated in the central region of Thailand, covering an area of about 622.303 square kilometers. It is located at the latitudes of 13 ° 45’ to 14 ° 04’ N and longitudes 100° 15’ to 100° 34’ E. The altitude ranges from 1 - 2 meters above the mean sea level. The physical feature of the land is essentially the river flood plain where Chao Phraya River flows through the eastern part of the province. The provincial town is only 20 kilometers west of Bangkok and is also included as a part of the Greater Bangkok. Nonthaburi is administratively divided into six districts namely Amphoe Muang Nonthaburi, Pak Kret, Bang Kruai, Bang Bua Thong, Bang Yai and Sainoi. The neighboring provinces are Changwat Phra Nakhon Si Ayutthaya and Pathum Thani to the north, Bangkok to the south and east, and Nakhon Pathom to the west (fig. 2.1).

2.1.1 Climate

The climate of the region is tropical, with the south western and north eastern monsoons. The annual climate is divided into three seasons as following:

1) Summer from mid February to mid May.

2) Rainy season, starting from mid May to October.

3) Winter from November to mid February.

The mean temperature is about 28-35 °C in summer, 25-30 °C in the rainy season and 20-28 °C in winter. The average relative humidity is ranging from 71-82 %. The mean annual rainfall is approximately 1,000 mm and the mean annual evaporation is about 1,800 mm. (from Meteorological Department, 2001)

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2.2 General Geology

Changwat Nonthaburi is a part of the Lower Central Plain, which geologically is a depressed area filled with the clastic sediments. The Aeromagnetic and borehole data indicate that overlying the basement complex are the unconsolidated and semi-consolidated sediments aged from Tertiary to Quaternary. During these periods the fluviatile and deltaic sediments deposited with occasional shallow marine environment. The total thickness of this rock sequence ranges from 400 m. to more than 1,800 m (Piancharoen and Chuamthaisong, 1976).

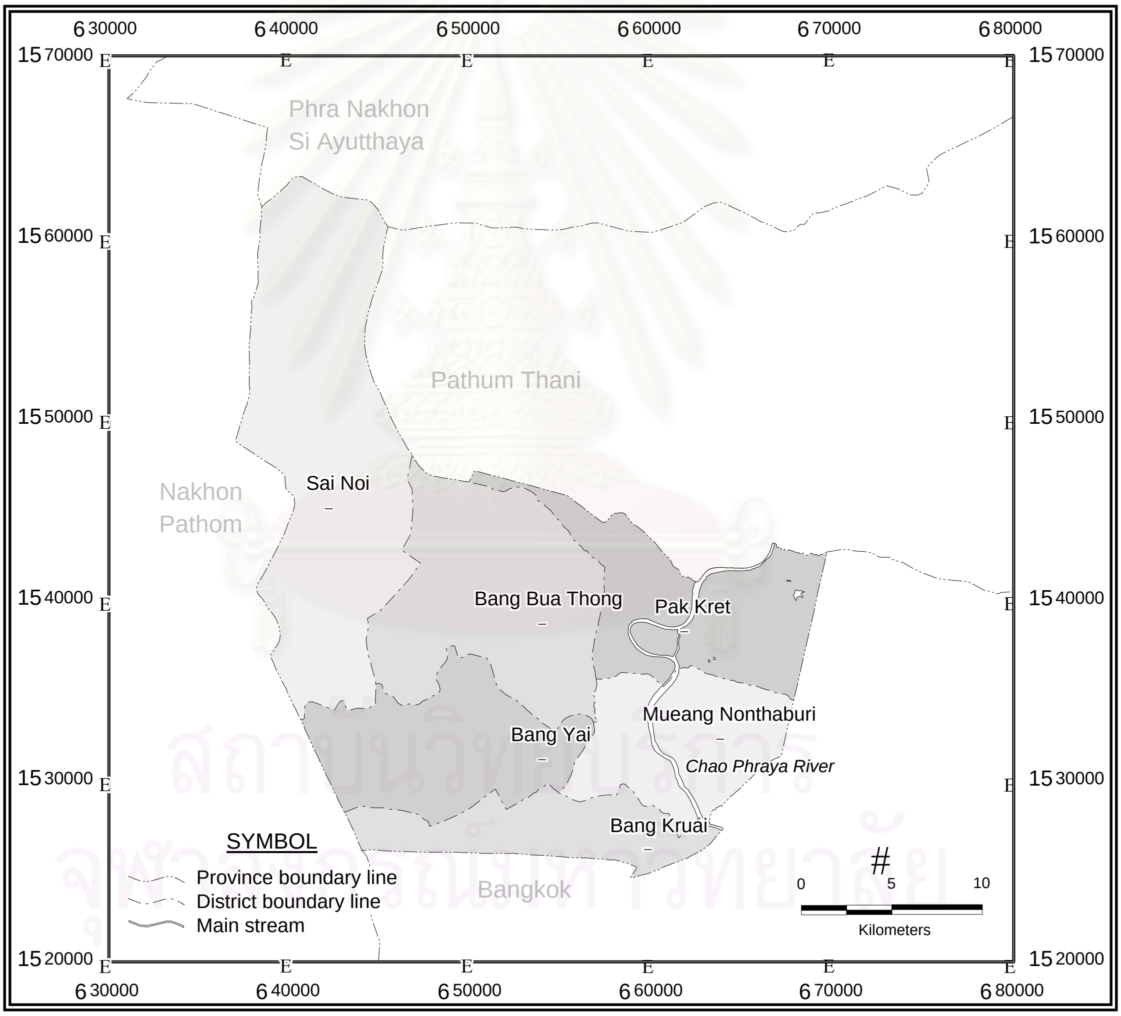

Figure 2.1. Changwat Nonthaburi and its administrative divisions.(DMR,2544)

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2.3 Hydrogeology

The groundwater in Changwat Nonthaburi is confined solely within the unconsolidated water bearing rock types, which are a part of Chao Phraya Basin sedimentary sequence. Piancharoen and Chuamthaisong (1976) classified the aquifer system according to the geological, hydrological and geophysical studied into 8 aquifers (fig 2.2), while the borehole logs and electric logs were used in identifying the aquifer system as well. It is generally assumed that each aquifer is fairly uniform in thickness and extents a long way out to the recharge area. The detail of the aquifer system is briefly described below:

2.3.1 Bangkok Aquifer

The Bangkok aquifer is the topmost of all aquifers and which the Bangkok clay overlies. It consists of a sequence of thin to thick layers of sand and gravel with many clayey lenses. The depth of the aquifer is about 15 to 30 m. from the existing ground surface while the thickness ranges from 20 to 60 m. This aquifer contains brackish to salty water, which is unsuitable for normal usage.

2.3.2 Phra Pradaeng Aquifer

The aquifer is separated from the Bangkok aquifer by a 10-15 m. clay bed. The average depth is 60-90 m. from the surface and the thickness varies from 20 to 50 m. The aquifer consists of white, coarse-grained sands and gravels with occasional clayey lenses and carbonized wood. The deposits were laid in the river mouth or very shallow sea, on an erosional surface of the hard and compacted older clay. The thickness of the aquifer decreases to the north. Groundwater in this aquifer is generally of high yield, however contains much brackish water due to the enchroachment of salty water toward the area of heavily utilization of the groundwater.

2.3.3 Nakhon Luang Aquifer

The aquifer is occurred under Phra Pradaeng Aquifer. It consists of permeable sands and gravels with some clayey lense and leaky clay beds. The depth from the present surface to the aquifer is about 120-150 m. and the average thickness is 50 m. The thickness is slightly decreases to the south. This aquifer is

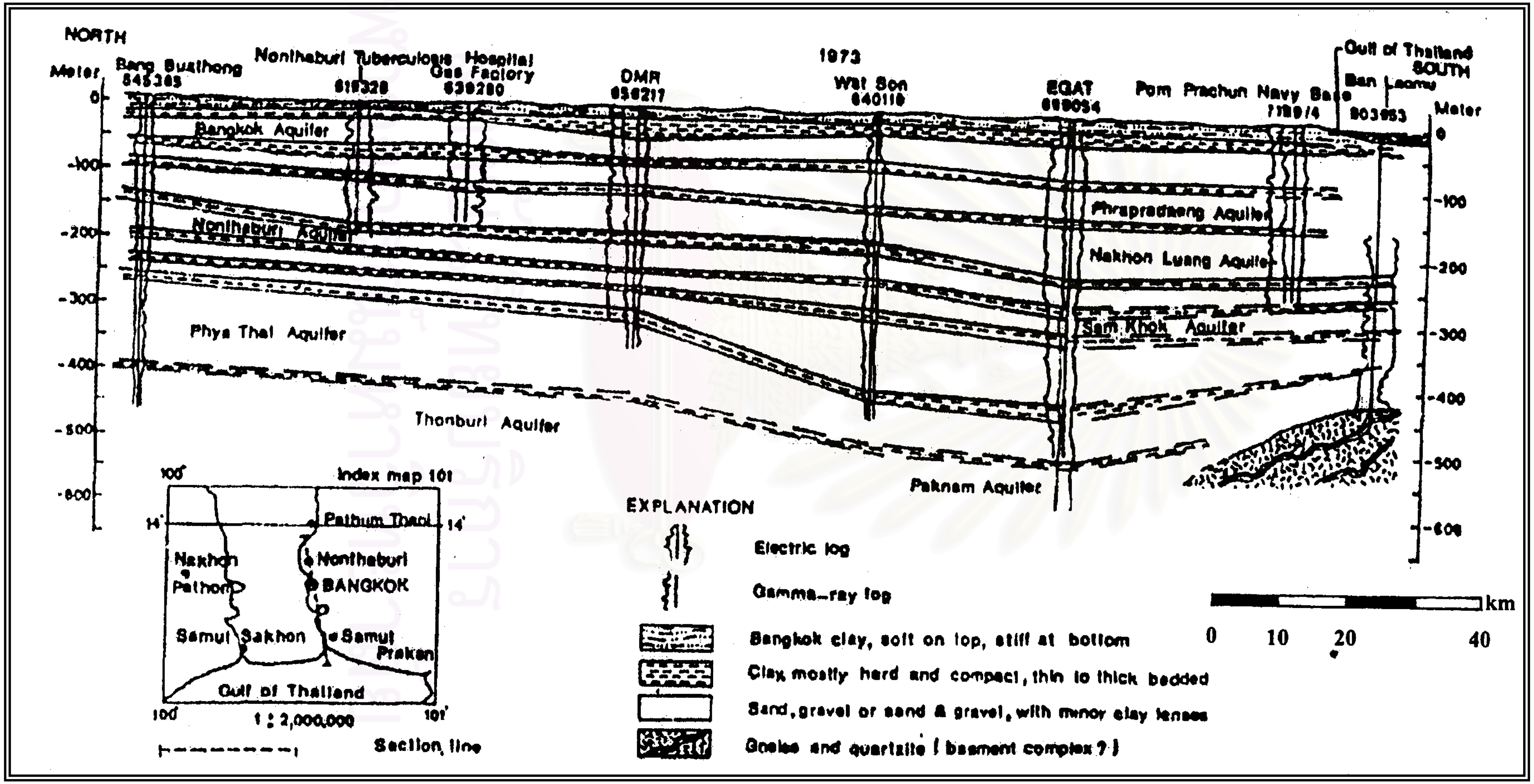

Figure 2.2 Hydrogeologic North-South section of the Lower Chao Phraya Delta showing principal aquifers below the Bangkok Metropolis. The cross-section was compiled from the Electric and Gamma- ray Logs by Piancharoen and Chuanthaisong (1976).

very permeable and gives good quality water in the area, especially east of Chao Phraya River.

2.3.4 Nonthaburi Aquifer

The aquifer is geologically similar to and conforms the Nakhon Luang aquifer. It is composed of sands and gravels with minor clayey lenses. The aquifer can be divided into at least 3 sub-aquifers separated by leaky clayey beds. The depth to the aquifer ranges from 170 to 200 m. and the thickness is about 30 to 70 m. The groundwater condition is quite similar to that of Nakorn Luang Aquifer. The groundwater development of this aquifer has increased rapidly since the Nakhon Luang aquifer has been damaged from heavily pumpage, which caused some deterioration of water quality.

2.3.5 Sam Khok Aquifer

The aquifer is found at a depth of about 300 m. The thickness ranges from 10 m. to 55 m. It consists of alternating layers of sands or gravels and clays. Clay are generally brown to yellow and moderately to highly compacted. Sands and gravels are generally medium to well sorted with intercalated clayey lenses. The aquifer yields good quality water in the north, east and southeast of Bangkok with slightly lesser amount than that of Nakorn Luang and Nonthaburi aquifers.

2.3.6 Phaya Thai Aquifer

The aquifer underlies Sam Khok aquifer and is separated from the above aquifer by a hard and compacted clayey bed, 5 to 10 m. thick. It consists of thin sand and gravel layers intercalated with clayey lenses. Sands and gravels are dirty brown, angular, medium-grained and poorly to fairly well sorted. The depth of the aquifer is 275 to 350 m. and the thickness is 40 to 66 m. The water bearing properties of the aquifer are similar to those of Sam Khoh Aquifer. Good quality water is found in the north, east and southeast of Bangkok. The aquifer is generally not much developed due to its great depth.

2.3.7 Thonburi Aquifer

The aquifer underlies a clay bed of 1 m. to 10 m. thick, which in turn underlies Phaya Thai aquifer. It consists of thick sands and gravels interbedded with thin layers of clay. Sands are coarse-grained, rounded and well sorted. Clays are generally pinkish to brown, compacted and sandy. The aquifer is 350 to 400 m. deep and 50 m. to 100 m. thick. Good quality water is found in the north, east and southeast of Bangkok but the aquifer is not as productive as other aquifers due to the presence of clay in many horizons.

2.3.8 Park Nam Aquifer

The aquifer is separated from Thonburi aquifer by a layer of leaky clay to sandy clay. It consists of at least 3 thick sand and gravel beds with clayey lenses. Sands and gravels are white to gray and well sorted. Clay layers are generally very compacted, olive gray to dark gray in color, and associated with some carbonaceous matters. The depth of the aquifer is about 550 m. and the thickness is about 30 m. The groundwater from this aquifer is considerably good both in terms of quality and quantity. The temperature of the water can be as high as 50 degrees celcius.

Presently, the groundwater from Phra Pradaeng, Nakhon Luang, Nonthaburi and Sam Khok aquifers are extensively utilized according to their high quantity as well as good quality. Bangkok aquifer, which is the shallowest aquifer, yields brackish to salty water while the other aquifers are too deep. They are not suitable for any development at this moment.

2.4 Nonthaburi Groundwater Potential

The unconsolidated water bearing rock type called **Qfd** (Quaternary flood plain deposits aquifer) or formerly designated as **Qcp** (Chao Phraya Aquifer) produces water at a rate of >20 m^3/hr throughout Nonthaburi area. The water is trapped in the voids between gravel and sand grains of flood plain and lower terrace deposits, consisting of multiple aquifers from the depth of 40 meters. Groundwater in Changwat Nonthaburi are produced from Phra Pradaeng, Nakhon Luang, Nonthaburi, Sam Khok and Phaya Thai aquifers at the depth 100-360 meters with static water level 10-45 meter. Good water quality is always produced from the depth of about 180 meter and below in Amphoe Muang Nonthaburi to the south and Amphoe Sainoi to the north. In the area of Amphoe Pak Kret and Amphoe Bang Yai, the depth of aquifer changes to about 300-360 meters.

A good (TDS < 500 mg/l) water quality is from an area covering about 70% of the entire provincial administrative area. A fair (TDS 500-1,500 mg/l) water quality is occupied about 15% and poor water quality (TDS > 1,500 mg/l) also accounted another 15%. This fair to poor quality water is found in the eastern side of Amphoe Bang Bua Thong.

2.5 Local Groundwater Potential

Since groundwater potential in Nonthaburi area is similar in every district in terms of water bearing rock, aquifer depth and water yielding capacity as well as water quality. Amphoe Sainoi, the area is the flood plain of the Chao Phraya River. Groundwater is found entirely in the Quaternary flood plain deposits aquifer (**Qfd**), from Nakhon Luang, Nonthaburi and Sam Khok aquifers are commonly discharged from a depth 140-300 meter. An average static water level is about 15-30 meter and average water yielding rate is more than 20 m^3/hr.

Good water quality containing TDS < 500 mg/l covers the entire Sainoi area. The mineral contents, in general, do not exceed the drinking water quality standard (Appendix V). Groundwater consumption rate of 50,000-100,000 m^3/yr for the household and over 100,000 m^3/yr for the industries at the ratio of 50:50.

Data of Geophysical log and borehole log of Department of Mineral Resource, Public Work Department and Thai Asia Pacific Brewery Co., Ltd. can be used identifying the aquifer system of Sainoi is shown in figure 2.3

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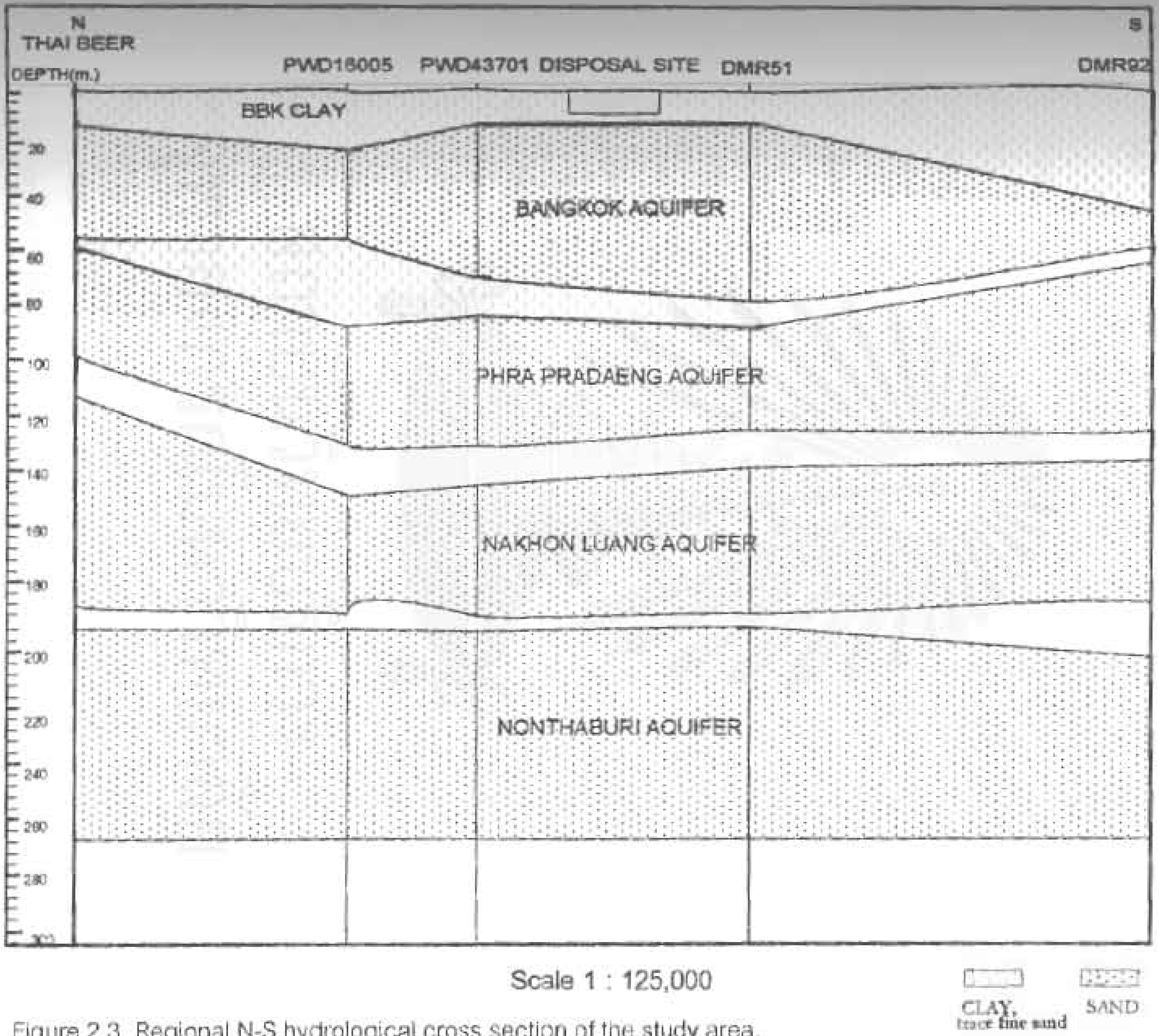

Figure 2.3. Regional N-S hydrological cross section of the study area.

CHAPTER III

SAINOI SOLID WASTE DISPOSAL SITE

3.1 Sainoi Disposal Site

Changwat Nonthaburi previously acquired two disposal sites for its several municipalities, being located in Amphoe Bang Bua Thong and in Amphoe Sainoi. Recently, Bang Bua Thong disposal site had already been closed because the site was filled up to its full capacity. Now the province dispose the solid waste only at the one in Amphoe Sainoi, the disposal site of the present study.

3.1.1 Background Information

3.1.1.1 The Study Area

The study area is located at Ban Khlong Kwang, Tambon Khlong Kwang, Amphoe Sainoi, Changwat Nonthaburi, at the latitude $13^{\circ}\ 58'\ 31''$ N and longitude $100^{\circ}\ 19'\ 40''$ E (fig. 3.1). The disposal site covers an area of 108,800 m^2 as 73,600 m^2 of dump waste and has been in service since 1982 (fig. 3.2). The site owned by the Provincial Administration Office of Changwat Nonthaburi.

3.1.1.2 Areal description

The area is a relatively-flat, low lying flood plain (fig 3.3), the paddy fields and vegetable farms surround the disposal site. North of the site, is a leachate collection pond, the south and west are the residential areas. An infectious incinerator is situated in the south of the disposal site. There are 2 important surface water resources, Khlong Na Mon flows from north to west and down to south of the disposal site, and Khlong Ha Roi in the east where the water flows from NE to SW. There is also an irrigated canal system surrounding the dump site, for providing water to the agricultural area, which are the paddy field and vegetation farms.

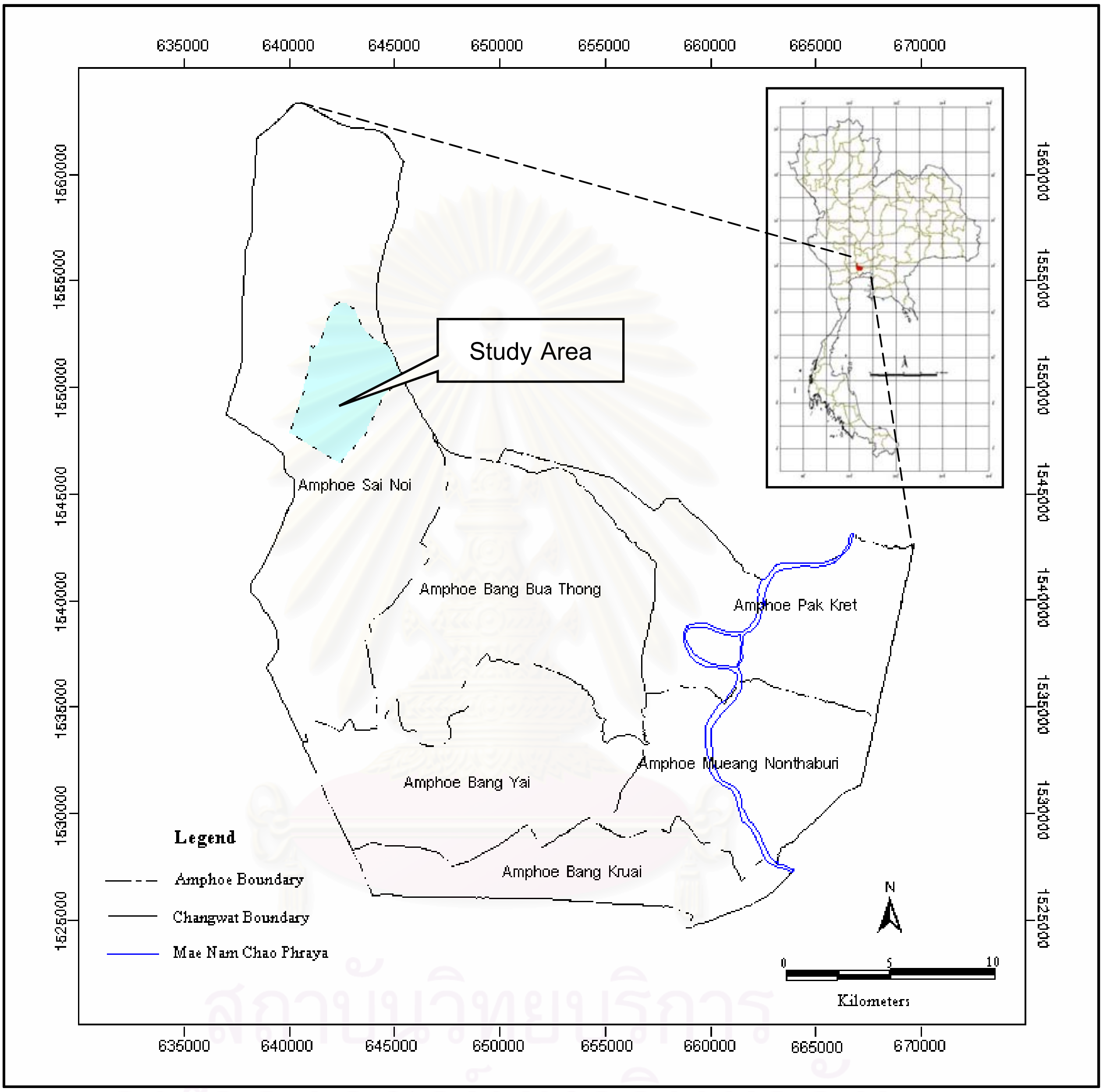

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Figure 3.1 Location of the study area.

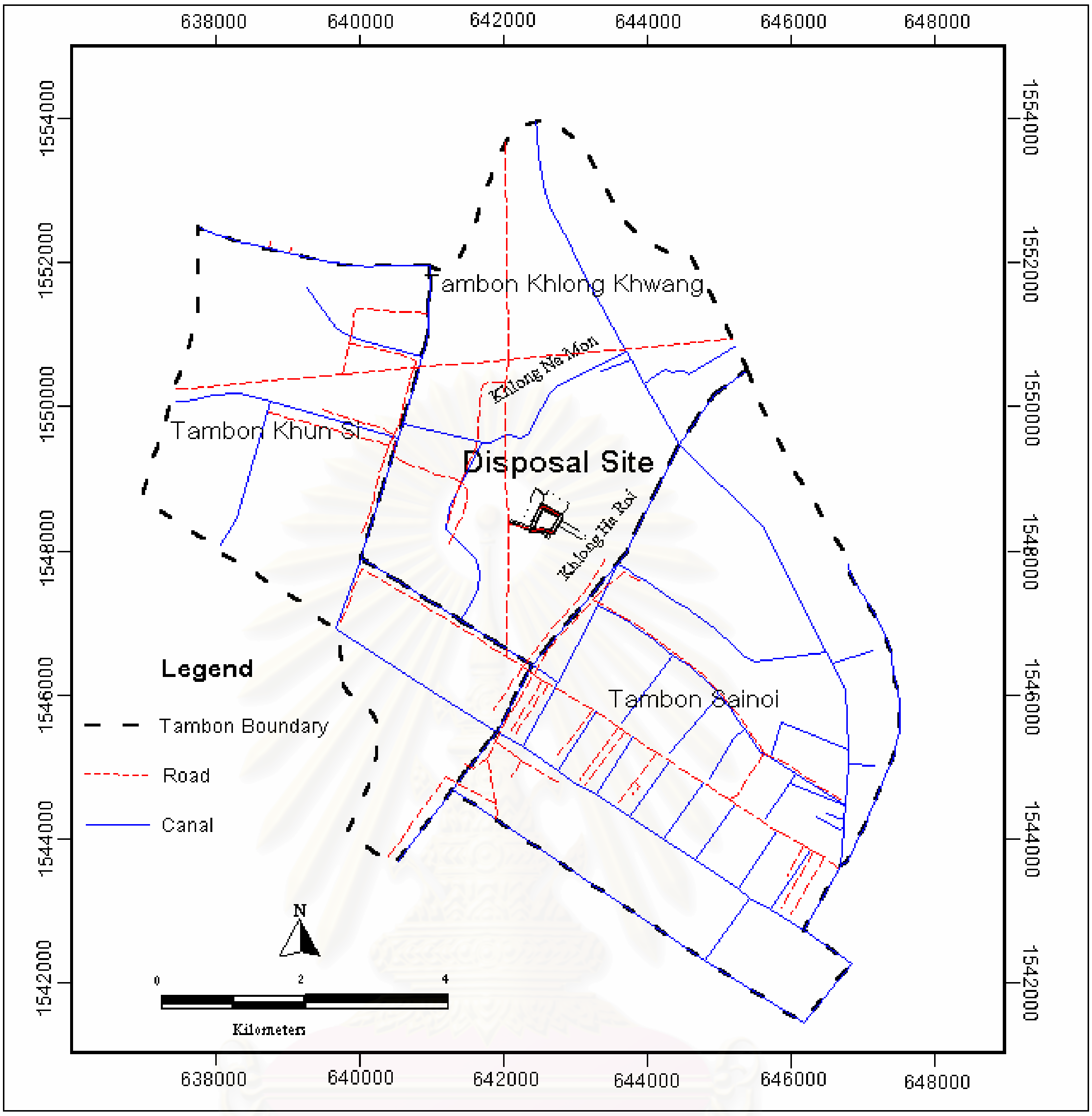

Figure 3.2 The location of the disposal site as referred to the study area in fig 3.1.

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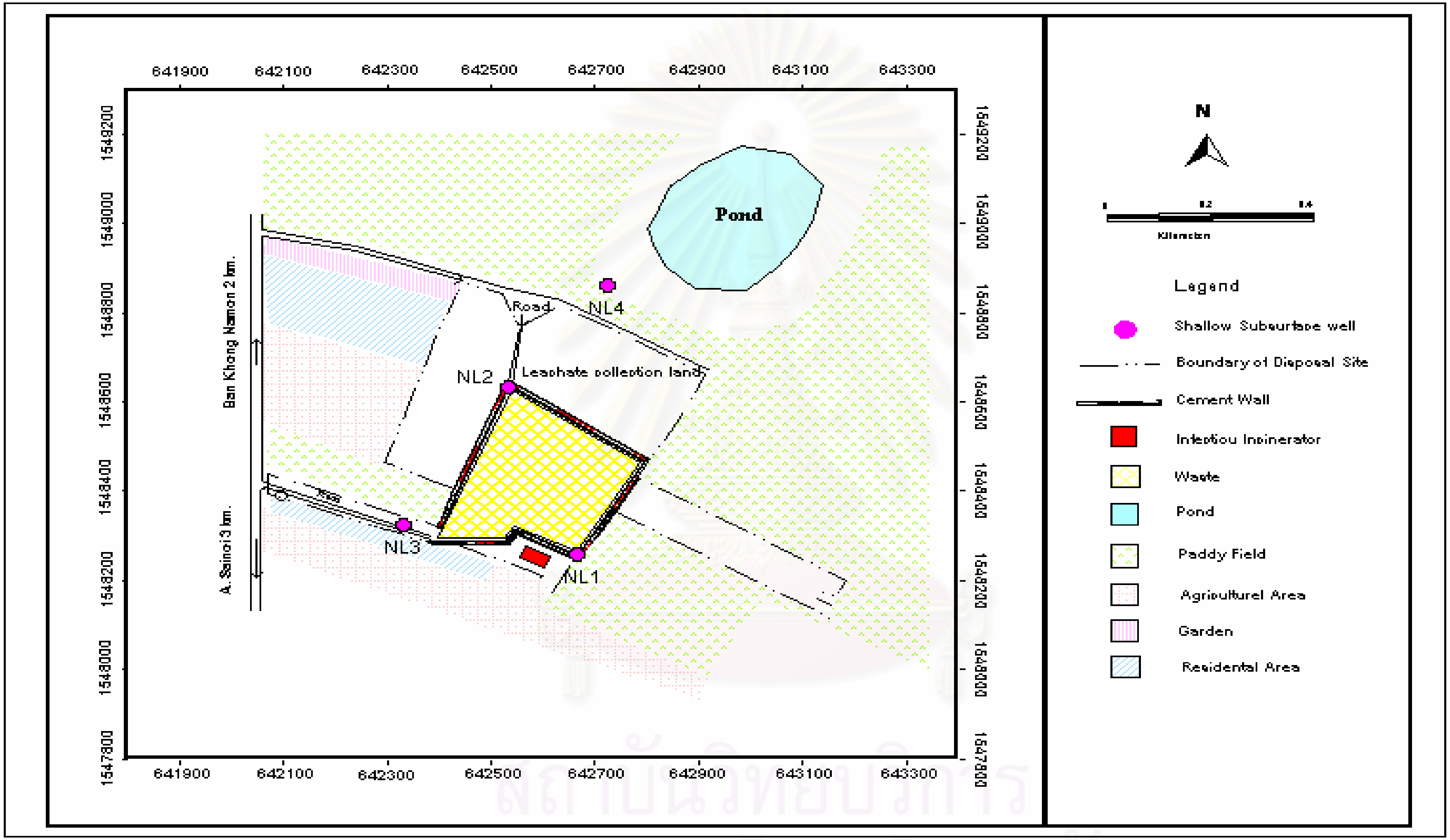

Figure 3.3 Land use of disposal site

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3.1.1.3 Soil Map

Most of the soil in the study area is Bang Khen series, according to the soil map (fig. 3.4) of Soil Survey Division, Land Development Department. The characteristics of the soil are

- very deep
- clay or silty clay.
- dark gray of black, over gray with brown, yellow red and red mottles over greenish gray at below 140 cm
- poor drainage
- low permeability with hydraulic conductivity < 0.5 cm./hour.
- period of water saturation
    - surface : 5-6 months
    - subsurface : 8-10 months, below 150 cm. depth : 1-3 months
- organic mater at 0-30 cm. : 1.5-2.5% (%carbon x 1.724)
- base saturation
    - at 0-30 cm : 35-75%
    - > 30 cm. : 35-75%
- CEC (Cation Exchange Capacity) (meg/100 gm. of soil)
    - at 0-30 cm. : >30
    - >30 cm. : 20-30
- available P
    - at 0-30 cm. : 6-10 ppm.
    - >30 cm. : 6-10 ppm.
- available K
    - at 0-30 cm. : > 120 ppm.
    - >30 cm. : > 120 ppm.
- pH
    - at 0-30 cm. : pH 5.5-7.0
    - >30 cm. : up to 7.0-8.0 in the very deep subsoil.

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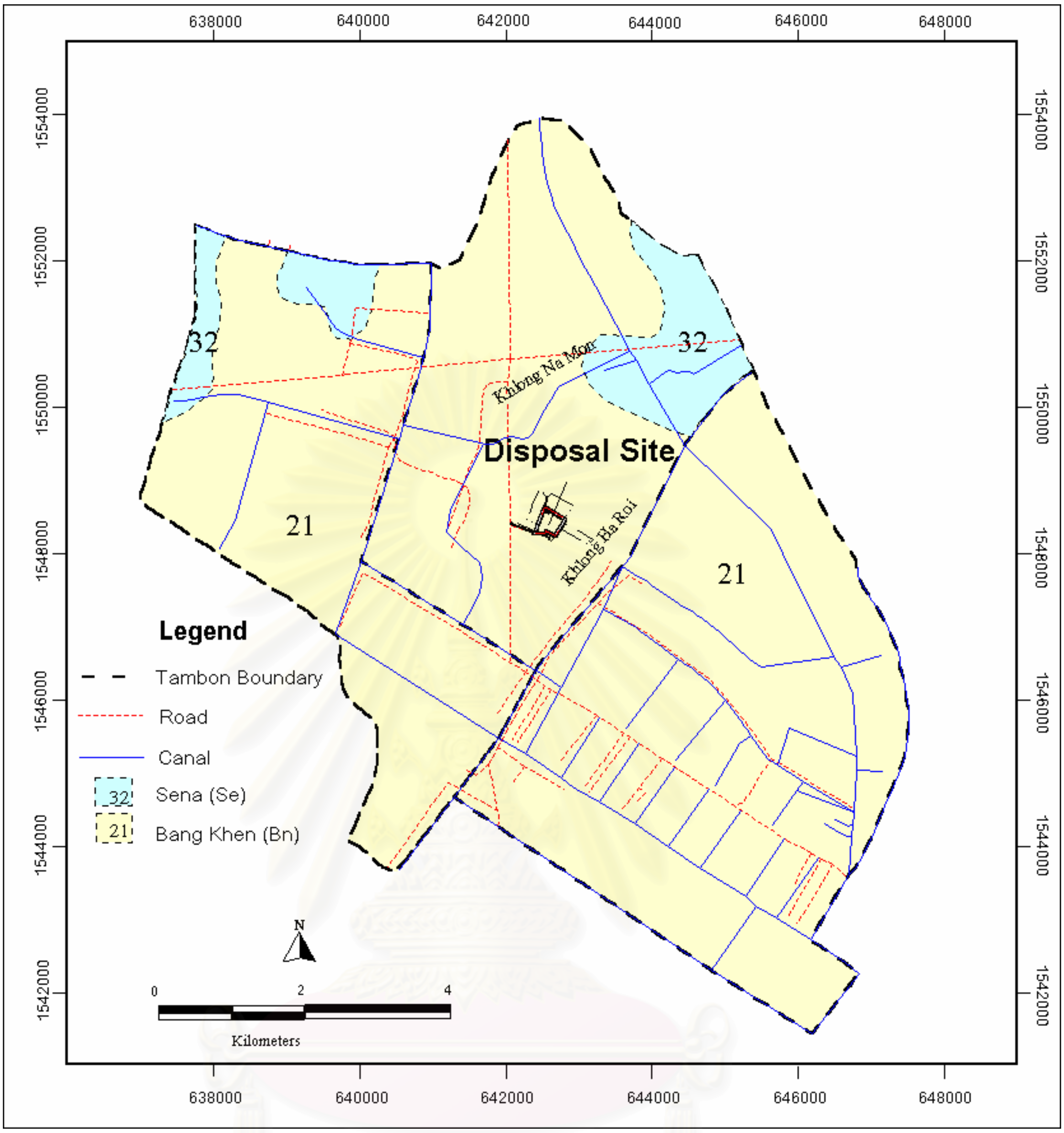

Figure 3.4 Soil map around the study area (Developed from the soil map of Soil Survey Division, Land Development Department).

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3.2 Sainoi Solid Waste Disposal

The solid wastes in the disposal site compose mainly of the household and municipal wastes, but certainly including some industrial and infectious wastes as well. As a general practice, the wastes are openly dumped and left uncovered for a natural decomposition. In the earlier period, the wastes were dumped into an excavated pit and piled up higher above the ground level. The sub-ground waste volume is 370,657 m^3, and 644,176.9 m^3 above the ground as surveyed in 1998 by Consultant of Technology Co, Ltd. The compaction rate of the wastes was rather high and non consistent as 20-30 cm. in 10 years. There is road system around the dump site, which was improved as concrete-surfaced in 2002 for the waste transportation route, to the dumpsite. A concrete wall was also constructed for preventing the leachate overflow out to the agriculture area nearby in the rainy season. The wall was built on the previous bund. Now the concrete wall is destroyed in some parts.

Table 3.1 summarized in detail of the solid wastes including the quantities, generating rate and components disposal at the site in 2001-2002.

Table 3.1 Solid waste quantities, generating rate and components in 2001 - 2002.

Changwat Nonthaburi	**Municipal solid waste components (% by weight)**										**P. (capital)**	**Q (kg. /day)**	**G. (kg./ capital /day)**
	Food remains	Paper	plastic	Glass	metal	rubber/ leather	fabric	Wood/ Leaf	rock/ ceramic	other			
1. Nontraburi N.M.	42.52	14.31	14.43	4.68	4.70	2.72	4.00	4.48	4.14	4.02	269,315	360,000	1.34
2. Pak kret N.M.	45.83	19.07	13.87	2.83	3.54	0.64	3.62	3.72	2.18	4.70	149,483	180,000	1.20
3. Bang Bua Thong M.M.	49.57	13.55	9.55	6.72	5.89	0.44	4.29	2.80	2.64	4.55	34,023	45,000	1.32
4. Bang Si Mueang T.M.	-	-	-	-	-	-	-	-	-	-	27,975	27,500	0.98
5. Sainoi T.M.	30.00	20.00	5.00	5.00	10.00	5.00	5.00	10.00	10.00	-	1,447	800	0.55
6. Bang Kruai T.M.	-	-	-	-	-	-	-	-	-	-	42,501	50,000	1.18
7. Plai Bang T.M.	-	-	-	-	-	-	-	-	-	-	18,808	30,000	1.60
8. Bang Yai T.M.	-	-	-	-	-	-	-	-	-	-	7,074	8,000	1.13
9. Bang Muang T.M.	-	-	-	-	-	-	-	-	-	-	4,915	6,000	1.22
10. Rat Niyom T.M.	-	-	-	-	-	-	-	-	-	-	1,349	810	0.60
Average / Total	41.98	16.73	10.71	4.81	6.03	2.20	4.23	5.25	4.74	3.32	556,890	708,110	1.27

(from Pollution Control Department, 2001)

Remark: N.M. is Nakhon Municipality, M.M is Muang Municipality and T .M. Tambon Municipality.

: P – population (Capital) ; Q- quantity of solid waste ; G - generating rate respectively.

: - unsorted solid waste components.

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3.3 Basement and Construction Data

3.3.1 Soil Type

Soil survey of the disposal site was conducted by the Consultant of Technology (1998) along with 13 testing bore-holes as shown in fig. 3.4. The 6 soil boring test are A-2, D-1, D-3, C-1, A-3 and D-3, and 3 monitoring wells, NL1, NL2 and NL3 drilled by Pollution Control Department give the additional information.

The cross-section lines are shown in fig. 3.5 reveal the cross-sectional profiles of the waste dump and the basement as appeared in figs 3.6 and 3.7. Line A-NL2-A' passes through NL1, D-1, D-3, Nl2 and C1 in direction of south to northwest and Line B-B' passes through A-3 and between D-3 and D-1 and NL3

3.3.2 Field Permeability Test

The field permeability test of the soil was carried out at B-4 and B-6 (figure 3.4) as follows.

1. Pour water into the drilled hole, diameter 3.88 cm, until the water level reach 70 cm.

2. Record the water level (Ht1) at 900 seconds (t1).

3. Record the final water level (Ht2) at 3600 seconds (t2).

4.Calculate the permeability using the formula in the table 3.2.

The permeability value of 2.8×10^{-5} to 8.5×10^{-5} cm/sec being calculated in Table 3.2 is considered to be rather low (table 3.3).

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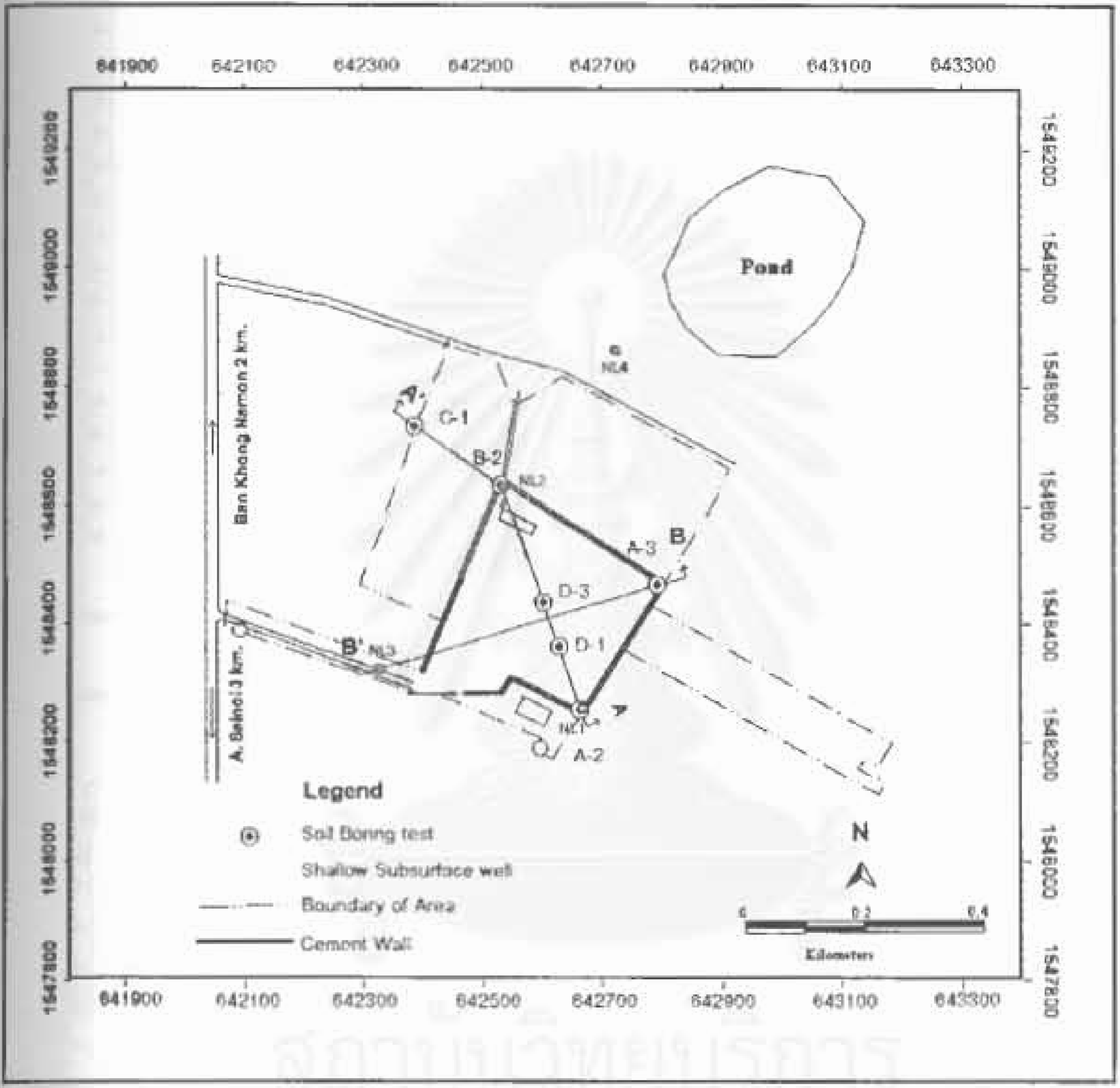

Figure 3.5. Positions of soil boring test and lines of cross-section (Developed from Consultants of Technology, 1998).

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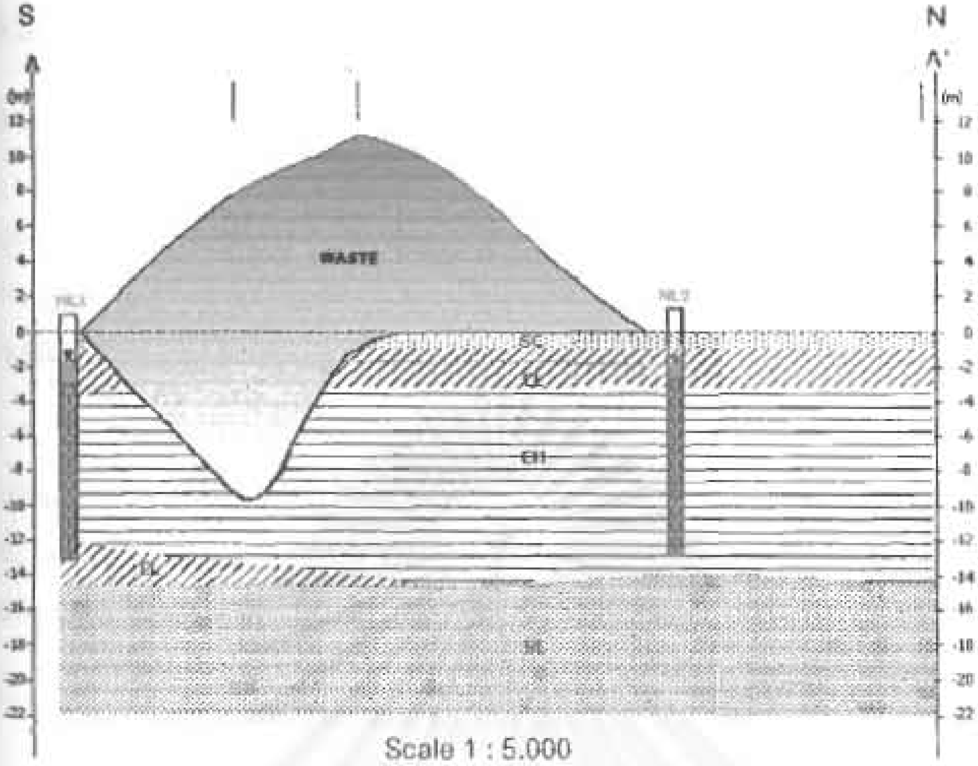
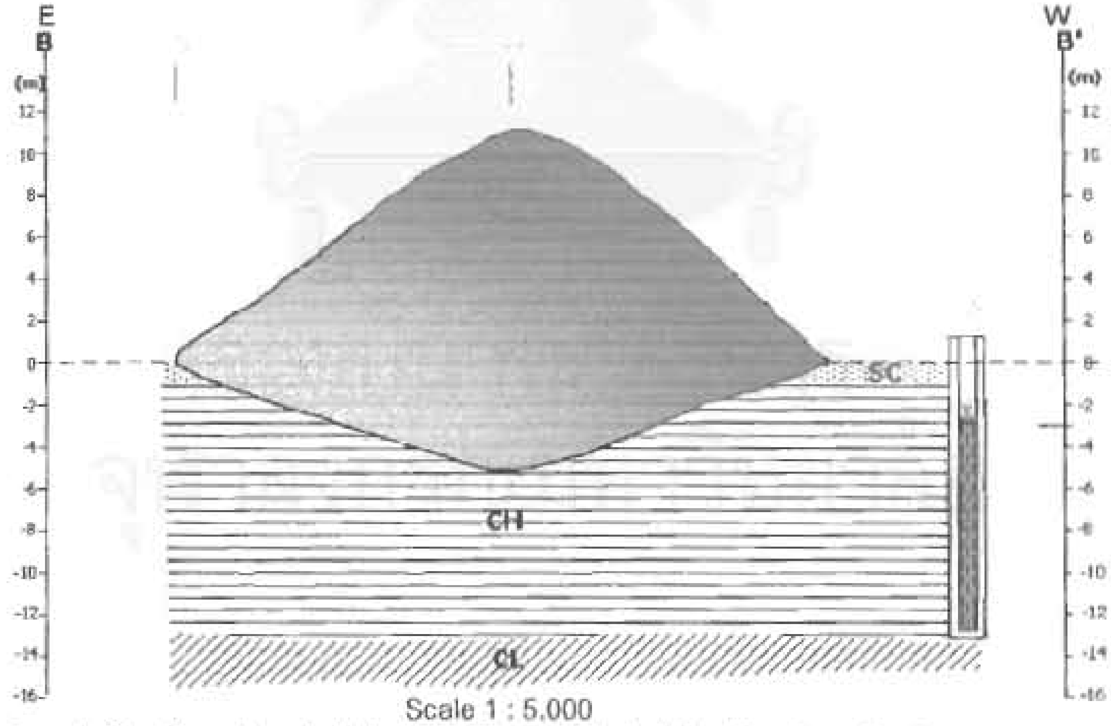


Remark: CL = Clay of low plasticity , CH = Clay of high plasticity, SC = clayey Sand

Figure 3.6. Cross – section along Line A-NL2-A' in Fig. 3.5. The cross-section is shown with the monitoring wells NL1 and NL2.



Remark: CL = Clay of low plasticity, CH = Clay of high plasticity, SC = clayey Sand

Figure 3.7 Cross - section along line B – B' in Fig. 3.5 The cross-section is shown with the monitoring wells NL3

Table 3.2 Variable Head Field Permeability Test.

Boring No.	Depth m.	R cm.	L cm.	Ho cm.	Head Ratio		Time, Sec		Ln = $\frac{L}{R}$	Ln = $\frac{H2}{H1}$	K = $\frac{R^2}{2L(t2-t1)}$ /Ln $\frac{L}{R}$ Ln$\frac{H2}{H1}$ cm/sec
					H1 = $\frac{Ht1}{Ho}$	H2 = $\frac{Ht2}{Ho}$	t1	t2			
B – 4	3.00	3.88	45	70	0.0286	0.0428	900	3,600	2.4508	0.4045	6.1416 x 10-5
	6.00	3.88	45	70	0.0286	0.0428	900	3,600	2.4508	0.4045	6.1416 x 10-5
B – 6	3.00	3.88	45	70	0.0714	0.0857	900	3,600	2.4508	0.1827	2.7739 x 10-5
	6.00	3.88	45	70	0.0571	0.1000	900	3,600	2.4508	0.5604	8.5086 x 10-5

(from Consultant of Technology,1998)

Ht1 = water level at starting time t1

Ht2 = water level at finishing time t2

H0 = water level before starring the testing

T1 = starting time, 900 seconds

T2 = finishing time, 3600 seconds

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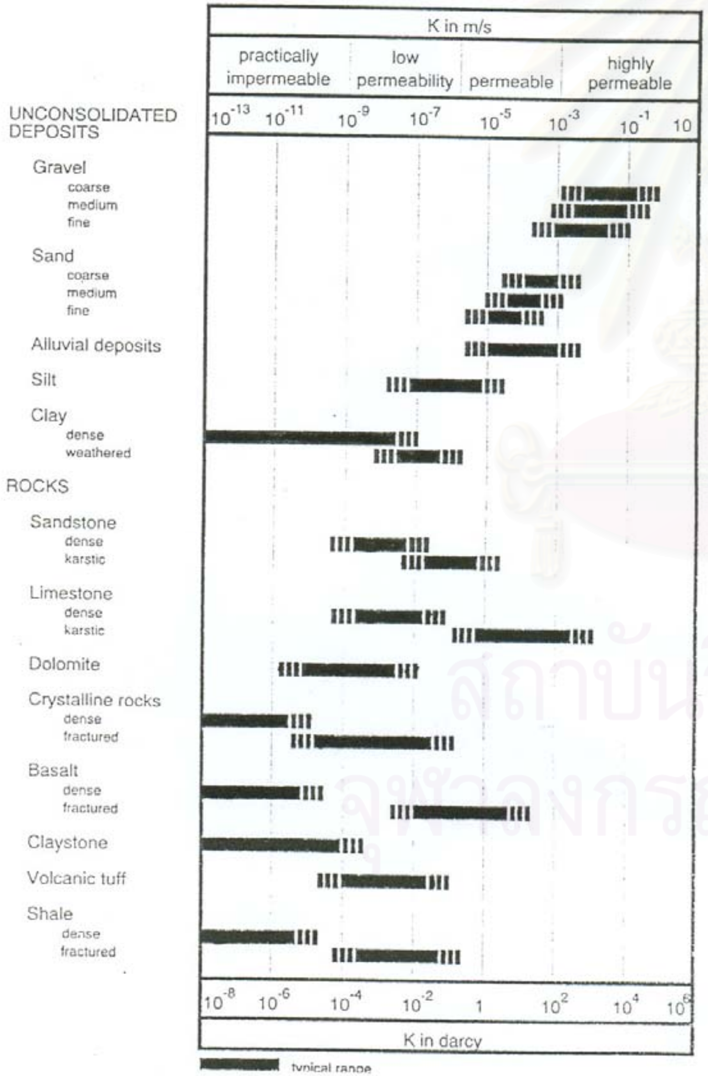
Table 3.3 Range of hydraulic conductivity of geological formation (Spitz and Moreno,1996)



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3.4 Monitoring Wells

Pollution Control Department had performed the soil core testing before designing the monitoring wells. The tube linings used in the monitoring wells are PVC pipes, diameter of 65 mm. and 13.5 m. long. They are perforated between 3-13 m. The wells are also installed with a protective steel casing, diameter 150 mm., from 1 m. depth through the bottom with cap on the top of casing to above the ground. The details of the 3 monitoring wells which passed through the different soil layers are shown in figure 3.8.

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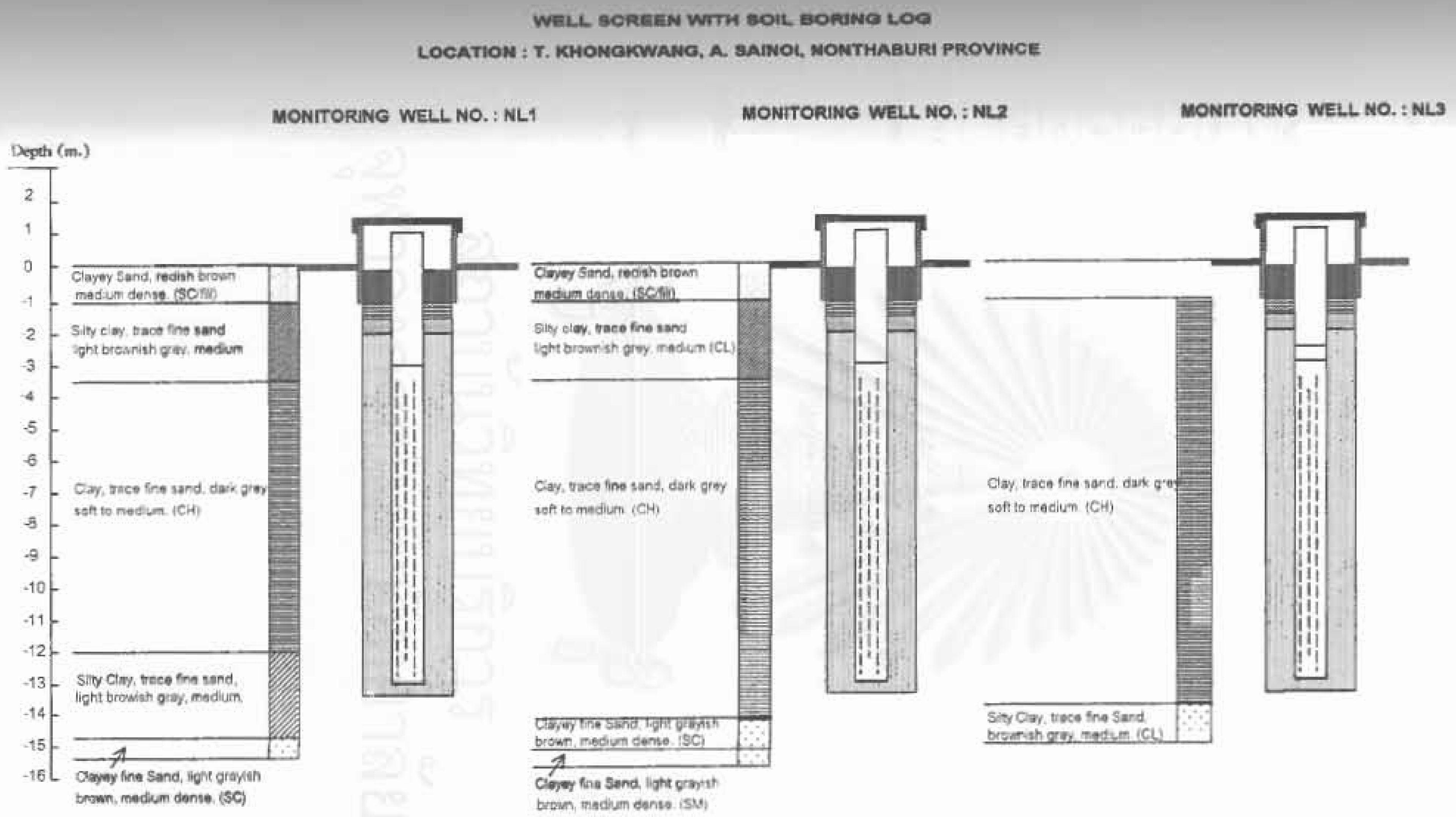

Figure 3.8. Three monitoring wells construction in the disposal site (From Pollution Control Department, 1998).

3.5 The Chemical Analysis Waste and Leachate

The chemical analysis of the compost wastes and the leachate under the waste mass was performed by Consultant of Technology (1998) as shown in Tables 3.4 and 3.5 below.

Table 3.4 Chemical analysis of compost waste

Parameter	Unit	Standard	Concentration of leachate	Remark	Total (mg/kg)
Chromium	mg/L Cr	0.05	0.049	✓	34.55
Cadmium	mg/L Cd	0.01	ND	✓	1.079
Nickel	mg/L Ni	0.1	0.009	✓	47.64
Iron	mg/L Fe	-	7.267	✓	25,232.72
Manganese	mg/L Mg	1.0	0.130	✓	210.95
Lead	mg/L Pb	0.05	ND	✓	38.45
Mercury	mg/L Hg	0.002	0.002	✓	0.361

(from Construction of Technology,1998)

Remark : Standard 40 CFR 1995 (USEPA)

✓ meet the standard **X** exceed the standard

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Table 3.5 Chemical analysis of heavy metal in leachate under waste disposal.

Sample	**Quality of heavy metal (mg/l)**						
	Pb	**Cd**	**Cr**	**Mn**	**Ni**	**Fe**	**Hg**
Standard (mg/l)	0.05	0.01	0.05	1.0	0.1	-	0.002
Soil under waste	ND	0.009	ND	2.20	ND	1.05	0.009
3	ND	0.009	ND	0.162	ND	7.997	0.0008
6	ND	0.010	0.044	0.064	ND	3.459	0.0007
9	ND	0.010	ND	0.078	ND	5.107	0.0003
12	ND	0.010	ND	ND	ND	0.032	0.0004
15	ND	0.008	0.092	ND	ND	0.019	0.0011
	NC	NC	SC	NC	NC	-	NC

(from Construction of Technology,1998)

Remark ND : Not Detectable

NC : Not Contaminated

SC : Slightly Contaminated

* 40 CFR 1995 (USEPA).

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3.6 Problems

A number of the existing problems caused by the Sainoi disposal site are as follows.

1) Large amount of leachate in the rainy season that sometimes flows into the paddy fields.
2) Nuisance problems from odor, flies, rats, smoke and vector.
3) Improper discard and uncollected municipal solid wastes.
4) Unintentionally mixing of hazardous waste with the municipal solid waste.
5) The waste from hospital is not sorted out.
6) Roads to disposal site being damaged due to the heavy trucks that transport the wastes.
7) Wastes fall from the trucks on to the road during handling.
8) Wastes have been on fired due to the dry weather
9) Aesthetics due to the huge pile of waste.

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CHAPTER IV

GENERAL KNOWLEDGES ON THE LEACHATE CONTAMINATION

4.1 Leachate Generation

Leachate is generated primarily by an infiltration of surface water into the refuse layers in a sanitary landfill. Also, leachate can be generated from the high original moisture in the waste itself, and subsurface water, which enters landfill produces the leachate too. The generated leachate will migrate into subsurface waters if the impermeable layers beneath the landfill are absent or inadequate. When the landfill slopes are steep with lack of final covering, leachate springs will result in contaminating the run-off and surface waters.

Physical, chemical, and biological factors in a landfill influence refuse decomposition rate and leachate generation rate and it's characteristics. The decomposition of landfill materials and leachate characteristics depend upon many factors, such as refuse composition, compaction, original moisture, inhibition of materials being presented, rate of water movement, temperature, etc. The rate of chemical and biological reaction in a landfill generally increases with temperature and moisture until an upper limit is reached. Landfill stabilization proceeds very slowly. Slow rates of decomposition are noticeable in extremely dry or in saturated landfills.

Basic factors influencing leachate generation is the climate of the area, it is note that the leachate quantity is proportional to the amount of net infiltration which, in turn, is a function of rainfall and evapotranspiration and other water losses at the site. The topography, soils, and hydrogeology of the site, vegetation and final covering, and the type of waste material in the landfill also play some good role in leachate formation. As for the effect of the climate, topography affects the run-off pattern and quantities of the water entering and leaving the landfill site and thus influences infiltration and leachate generation. Soil type of the site area also influence the quantities of water infiltration through the landfill. Leachate quantities increase as the permeability of soil beneath the landfill and soil used for intermediate and final cover increases.

Qasim and Burchinal (1970) concluded that although deeper fills produced leachate with higher concentrations of BOD, ammonia nitrogen and organic nitrogen, chloride, iron, sodium, and magnesium, the concentration of pollutants in such liquids per unit depth of fill decreased as the depth of fill increased. They found that, in general, deeper fills will absorb more water before leaching occurs, but take a longer time to decompose, and so produce leachate over a longer period of time than shallower fills of similar surface area and under similar conditions of precipitation and percolation.

The quantity of leachate generated from a sanitary landfill site is highly variable and depends upon the design of the landfill site and methods of operation and management of the system. The water or moisture balance method (Dass et al. 1977) available for estimating the rate of leachates generation can be expressed by

$$Pp = P - R - AET - \Delta S$$

Where

Pp = moisture percolate to the solid waste (mm)

P = precipitation (mm)

R = surface runoff (mm)

AET = actual evapotranspiration over the landfill surface (mm)

ΔS = the gain in the moisture storage within the soil (mm).

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4.2 Physical Processes Controlling the Transport of Contaminants in the Aqueous Phase in the Subsurface

4.2.1 Advection-Dispersion Theory

The study of advection and dispersion processes is useful for predicting the time when an action limit, i.e., a concentration limit used in regulations such as drinking water standard, will be reached. Knowledge of advection-dispersion also can be used to select technically accurate and cost-effective remedial technologies for contaminated aquifers.

If concentrations of a contaminant were measured in a monitoring well that was located between a contaminant source and a receptor such as a water supply well, a graph of concentrations versus time would show a breakthrough curve, i.e., the concentrations do not increase in a step-function (i.e., plug flow), but rather in an S-shaped curve (figure 4.1). In a one-dimensional, homogeneous system, the arrival of the center of the mass is due to advection, while the spread of the breakthrough curve is the result of dispersion (Palmer and Johnson, 1989a).

Advection

Advection is defined by the transport of a non-reactive, conservative tracer at an average ground-water velocity (Palmer and Johnson, 1989a). The average linear velocity is dependent on (1) the hydraulic conductivity of the subsurface geologic formation in the direction of subsurface water flow, (2) the porosity of the formation, and (3) the hydraulic gradient in the direction of subsurface water flow. For waste contaminants that react through precipitation/dissolution, adsorption, and/or partitioning reactions within the subsurface formation, the velocity can be different from the average subsurface water velocity

Dispersion

Dispersion of waste contaminants in an aquifer causes the concentration of contaminants to decrease with increasing length of flow (U.S. Environmental Protection Agency, 1985). Dispersion is caused by (1) molecular diffusion (important only at very low velocities), and (2) hydrodynamic mixing (occurring at higher velocities in laminar flow through porous media). Contaminants traveling through porous media have different velocities and flow paths with different lengths. Contaminants moving along a shorter flow path or at a higher velocity, therefore, arrive at a specific point sooner than contaminants following a longer path or traveling at a lower velocity, resulting in hydrodynamic dispersion.

Figure 4.1 shows that dispersion can occur in both longitudinal (in the direction of subsurface water flow) and transverse (perpendicular to subsurface water flow) directions, resulting in the formation of a conic waste plume (fig. 4.2) downstream from a continuous pollution source (U.S. Environmental Protection Agency, 1985). The concentration of waste contaminants is less at the margins of the plume and increases towards the source. A plume will increase in size with more rapid flow within a time period, because dispersion is directly related to subsurface water velocity.

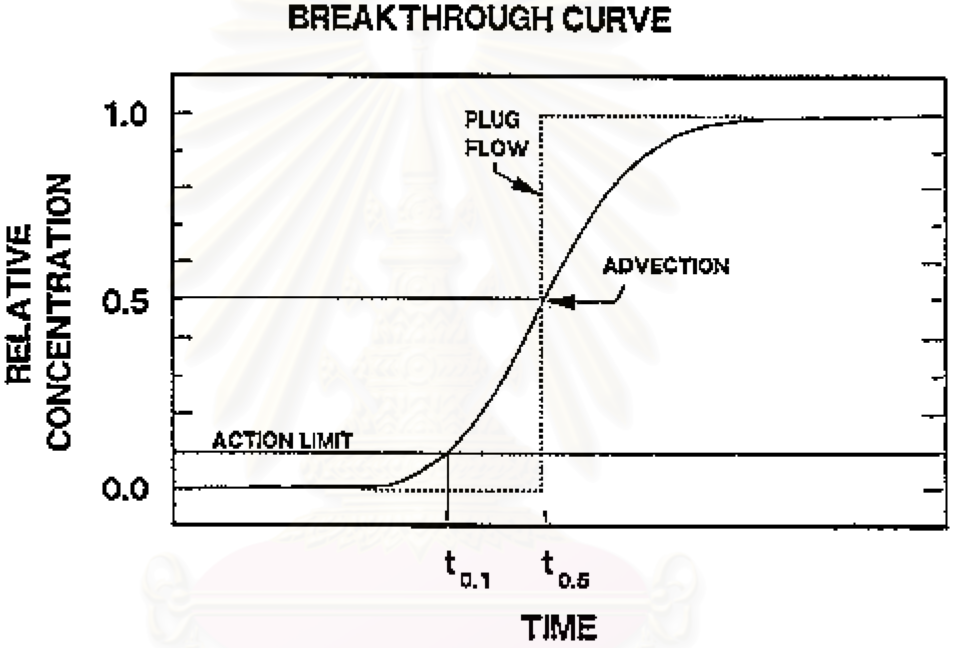

Figure 4.1. Breakthrough Curve for a contaminant, as measured in a monitoring well (Palmer and Johnson, 1989a)

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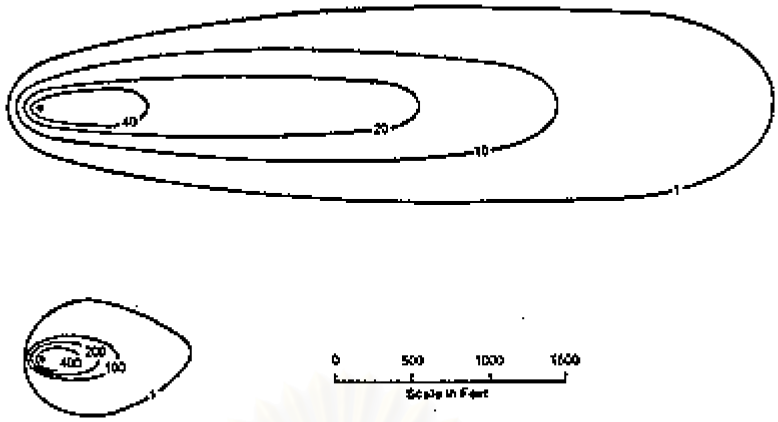

Figure 4.2 The effects of ground-water velocity on plume shape. Upper plume velocity: 1.5 ft/day and lower plume velocity: 0.5 ft/day (US.Environmental Protection Agency, 1985).

The dispersion coefficient varies with subsurface water velocity. At low velocity, the dispersion coefficient is relatively constant, but increases linearly with velocity as subsurface water velocity increases. Based on these observations, investigators proposed that the dispersion coefficient can be expressed as a sum of an effective molecular diffusion coefficient and a mechanical dispersion coefficient (Palmer and Johnson, 1989a).

The effective molecular diffusion coefficient is a function of the solution diffusion coefficient and the tortuosity of the medium. Tortuosity accounts for the increased distance a diffusing ion must travel around sand grains. The mechanical dispersion coefficient is proportional to velocity. Specifically, mechanical dispersion is a result of (1) velocity variations within a pore, (2) different pore geometries, and (3) divergence of flow lines around sand grains present in a porous medium (Gillham and Cherry, 1982).

The term dispersivity is oftenly confused with dispersion. Dispersivity does not include velocity, so to convert dispersivity to dispersion requires multiplication by velocity. Since dispersion is dependent on site-specific velocity parameters and configuration of pore spaces within an aquifer, a dispersion coefficient should be determined experimentally or empirically for a specific aquifer. The selection of appropriate dispersion coefficients that adequately reflect existing aquifer

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conditions is critical to the success of chemical transport modeling (U.S. Environmental Protection Agency, 1985).

4.2.2 Advection-Dispersion Equation

An advection-dispersion equation is used to express the mass balance of a waste contaminant within an aquifer as a result of dispersion, advection, and change in storage. The mass balance is a function of the dispersion coefficient, the ground-water velocity, concentration of the contaminant, distance, and time (Palmer andJohnson,1989a). An advection-dispersion equation can be applied to the description of three dimensional transport of waste contaminants in an aquifer, using three dispersion coefficients (one longitudinal and two transverse). Mathematically detailed descriptions of the advection-dispersion equation are presented in Bear (1969, 1979).

Discrepancies between results generated from advection-dispersion equations and laboratory and field experiments have been found. These discrepancies have been attributed to (1) immobile zones of water within the aquifer, (2) solution-solid interface processes, (3) anion exclusion, and (4) diffusion in and out of aggregates (Palmer and Johnson, 1989a).

Field observations using field tracer studies also have shown that longitudinal dispersivity values are usually much larger than transverse dispersivity measurements (Palmer and Johnson, 1989a). Figure 3.3 shows three dimensional field monitoring that has corroborated these observations by identifying long, thin contaminant plumes rather than plumes spread over the thickness of an aquifer. (Kimmel and Braids, 1980, MacFarlane and others, 1983). The large longitudinal dispersion coefficients are thought to result from aquifer heterogeneity. In an ideally stratified aquifer with layers of sediment of different hydraulic conductivities, contaminants move rapidly along layers with higher permeability and more slowly along the lower permeability layers (figure 4.4) (Palmer and Johnson, 1989a). Sample concentration of a contaminant is an integration of the concentrations of each layer, if water is sampled from monitoring wells that are screened through the various layers.

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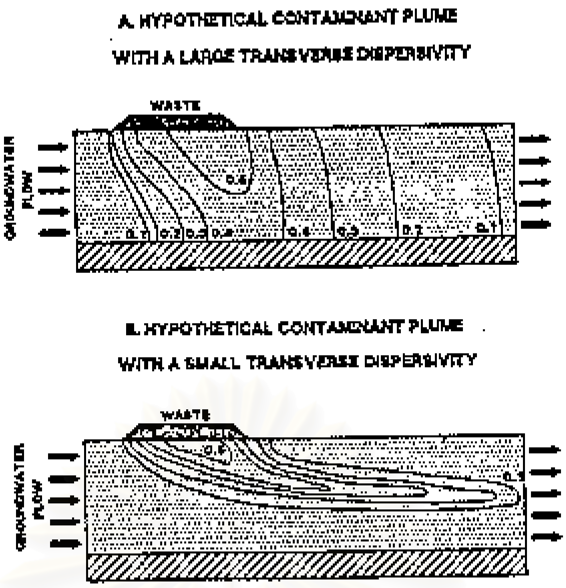

Figure 4.3 Hypothetical contaminant plumes for large (A) and small (B) Dispersivities (Palmer and Johnson, 1989a)

Results from plotting concentration versus distance show a curve with large differences in concentrations, even though only advection is considered. This dispersion is the result of aquifer heterogeneity and not pore-scale processes.

However, defining hydraulic conductivities in the subsurface is difficult, since not all geologic formations are perfectly stratified, but may contain cross stratification or graded bedding (Palmer and Johnson, 1989a). To quantify the heterogeneity in an aquifer, hydraulic conductivity is considered to be random, and statistical characteristics, such as mean, variance, and autocorrelation function, are determined.

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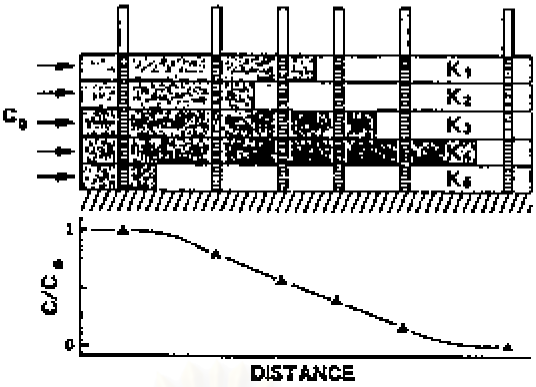

Figure 4.4 Contaminant Distributions and Concentrations In an Ideally Stratified Aquifer (after Gillham and Cherry, 1982, by Palmer and Johnson, 1989a)

In addition to aquifer heterogeneity, other processes, untributing to the spread of contaminants include (1) diverging flow lines resulting in the spread of contaminants by advection over a larger cross section of the aquifer, (2) temporal variations in the water table resulting in change of direction of subsurface water flow and lateral spread of contamination, and (3) variations of concentration of contaminants at the source resulting apparent dispersion in the longitudinal direction (Frind and Hokkanen, 1987; Palmer and Johnson, 1989a).

Subsurface water sampling methods may also result in avection of apparent spreading of contaminant plumes (Palmer and Johnson, 1989a). An underestimation of contaminant concentrations at specific locations in an aquifer may be due to insufficient well-purging. Monitoring wells with different screen lengths that integrate subsurface water from different sections of the aquifer may yield dissimilar contaminant concentrations.

4.2.3 Diffusive Transport through Low Permeability Materials

In materials with low hydraulic conductivities (e.g., unfractured clays and rocks with conductivities less than 10^{-9} m/s), diffusive transport of waste contaminants is large compared to advective transport (Neuzil, 1986, Palmer and Johnson, 1989a). Contaminants can diffuse across natural aquitards or clay liners with low hydraulic conductivities, resulting in aquifer contamination. The extent of movement is dependent on diffusive flux, rate of subsurface water flow in the aquifer, and the length of the source area.

4.2.4 Effects of Density on Transport of Contaminants

The density of a contaminant plume may contribute to the direction of solute transportation if dissolved concentrations of contaminants are large enough (Palmer and Johnson, 1989a). For example, assuming that the density of subsurface water within an aquifer is 1.00, the natural horizontal gradient is 0.005, and the natural vertical gradient is 0.000, if the density of the contaminant plume is equal to the density of the subsurface water, the plume moves horizontally with the naturally existing hydraulic gradient. If the density of the contaminated water is 1.005 (a concentration of approximately 7,000 mg/l of total dissolved solids), then the driving force in the vertical direction is the same as the driving force in the horizontal direction. If the aquifer is isotropic, then the resulting vector of these two forces descends at 45 degrees into the aquifer. The contaminant plume moves deeply into the aquifer and may not be detected with shallow monitoring systems installed under the assumption of horizontal flow.

4.2.5 Retardation of Contaminants

If contaminants undergo chemical reactions while being transported through an aquifer, their movement rate may be less than the average subsurface water flow rate (Palmer and Johnson, 1989a). Such chemical reactions that slow down the movement of contaminants in an aquifer include precipitation, adsorption, ion exchange, and partitioning into organic matter or organic solvents. Chemical reactions affect contaminant breakthrough, as shown in Figure 4.5. If the retardation factor, R (calculated from equations for contaminant transport that include retardation), is equal to 1.0, the solute is nonreactive and moves with the subsurface water. If R is greater than 1.0, the average velocity of the solute is less than the velocity of the subsurface water, and the dispersion of the solute is reduced. If a monitoring well is located a distance from a contaminant source such that a nonreactive solute requires time, t1, to travel from the source to the well, a contaminant with a retardation factor of 2 will require 2t1 to reach the well, and 4t1 will be required for a contaminant with a retardation factor of 4.

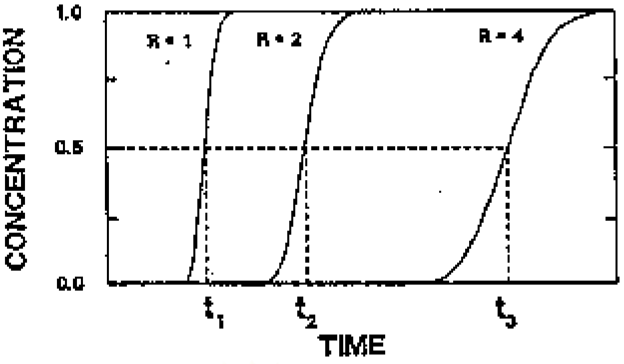

Figure 4.5 Time Required for Movement of Contaminants at Different Retardation Factors (Palmer and Johnson, 1989a)

Contaminants with lower retardation factors are transported at the greater distances over a given time than contaminants with larger retardation factors (Figure 3.6) (Palmer and Johnson, 1989a). A monitoring well network has a greater chance of detecting contaminants with lower retardation factors because they are found in a greater volume of the aquifer. Estimation of the total mass of a contaminant with a retardation factor of 1.0 in an aquifer may be more accurate than estimation for contaminants with greater amounts of retardation. Therefore, estimation of time required to remove non-reactive contaminants may be more accurate than time estimation for retarded contaminants. The slow movement of retarded contaminants may control the time and costs required to remedial a contaminated aquifer.

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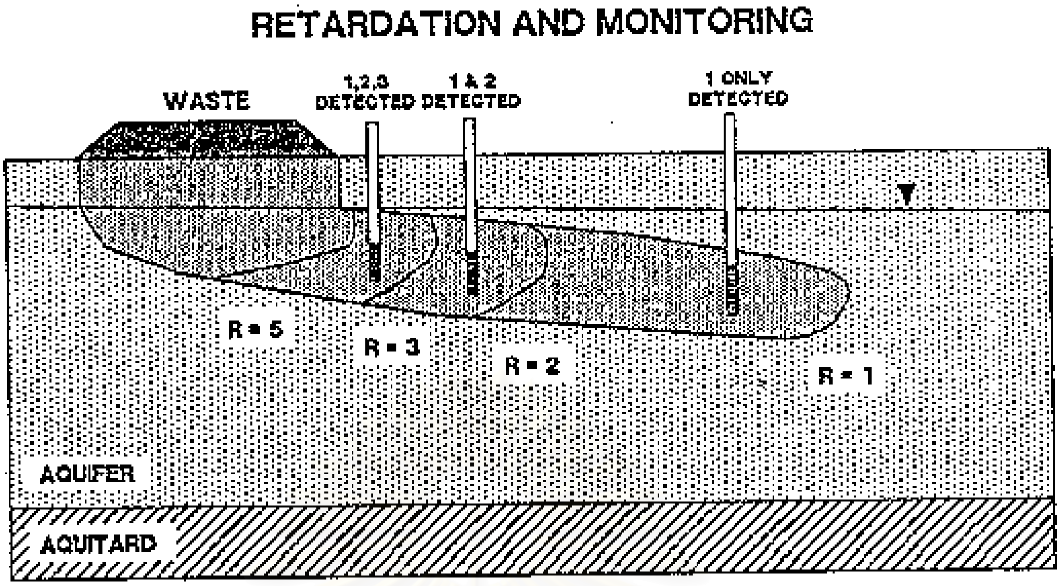

Figure 4.6. Transport of Contaminants with Varying Retardation Factors at a Waste Site (Palmer and Johnson, 1989a)

4.3 Chemical Processes Controlling the Transport of Contaminants in the Subsurface

Subsurface transport of contaminants often is controlled by complex interactions between physical, chemical, and biological processes. The advection-dispersion equation used to quantitatively describe and predict contaminant movement in the subsurface also must contain reaction terms added to the basic equation to account for chemical and biological processes important in controlling contaminant transport and fate (Johnson and others, 1989).

4.3.1 Chemical Reactions of Inorganic Compounds

In studies of organic contamination, the most important characteristic is the total concentration of a contaminant in a certain phase (e.g., in water versus aquifer solid materials). However, studies of inorganic contamination are often more difficult because inorganic materials can occur in many chemical forms, and knowledge of these forms (i.e., species) is required to predict their behavior in subsurface water (Morel, 1983; Sposito, 1986).

In subsurface water, an inorganic contaminant may occur as (1) "free ions" (i.e., surrounded by only water molecules), (2) insoluble species (3) meta Vligand complexes, (4) adsorbed species, (5) species held on a surface by ion exchange, or (6) species differing by oxidation state (e.g., manganese (II) and (IV) or chromium (III) and (VI) (Johnson and others, 1989).

The total concentration of an inorganic compound may not provide sufficient information to describe the fate and behavior of that compound in subsurface water. Mobility, reactivity, biological availability, and toxicity of metals and other inorganic compounds depend upon their speciation (Johnson and others, 1989). The primary reactions affecting the speciation of inorganic compounds are solubility and dissolution, complexation reactions, adsorption and surface chemistry, ion exchange, and redox chemistry.

Solubility, Dissolution, and Precipitation. Dissolution and weathering of minerals determine the natural composition of subsurface water (Johnson and others, 1989). Dissolution is the dissolving of all components within a mineral, while weathering is a partial dissolution process in which certain elements leach out of a mineral, leaving others behind.

Mineral dissolution is the source of most inorganic ions in subsurface water. In principle, a mineral can dissolve up to the limits of its solubility, but in many cases, reactions occur at such a slow rate that true equilibrium never is attained (Morgan, 1967).

The weathering of silicate minerals contributes cations, such as calcium, magnesium, sodium, potassium, and silica, to water and forms secondary weathering products such as kaolinite and montmorillonite clays (Johnson and others, 1989). This weathering increases the alkalinity of subsurface water to a level greater than its rainwater origins.

Weathering and dissolution also can be a source of contaminants. The opposite of dissolution reactions is precipitation of minerals or contaminants from an aqueous solution (Johnson and others, 1989). During precipitation, the least-soluble mineral at a given pH level is removed from solution. An element is removed by precipitation when its solution concentration saturates the solubility of one of its solid compounds. If the solution concentration later drops below the solubility limit, the solid will begin to dissolve until the solubility level is attained again. Contaminants may initially precipitate, then slowly dissolve later after a remedial effort has reduced the solution concentration, thus complete remediation of the aquifer may require years.

A contaminant initially may be soluble but later precipitate after mixing with other waters or after contact with other minerals (Drever, 1982; Williams, 1985; Palmer, 1989). For example, pumping water from an aquifer may mobilize lead until it converges and mixes with waters high in carbonates from a different formation and precipitates as a lead carbonate solid.

Complexation Reactions. In complexation reactions, a metal ion reacts with an anion that functions as a ligand (Johnson and others, 1989). The metal and the ligand bind together to form a new soluble species called a complex. Transition metals form the strongest complexes (Stumm and Morgan, 1981); alkaline earth metals form only weak complexes, while alkali metals do not form complexes (Dempsey and O'Melia, 1983). The approximate order of complexing strength of metals is:

Fe(III)> Hg> Cu> Pb> Ni> Zn> Cd>
Fe(II)» Mn> Ca> Mg

Common inorganic ligands that bind with metals include: OH^-, Cl^-, $S0_4^{2-}$, $N0_3^-$, S^{2-}, F^-, NH_3, $P0_4^{3-}$, CN^-, and polyphosphates. Their binding strength depends primarily on the metal ion with which they are complexing (Johnson and others, 1989). Inorganic ligands are usually in excess compared to the "trace" metals with which they bind, and, therefore, they affect the fate of the metals in the environmental system, rather than vice versa (Morel, 1983).

Organic ligands generally form stronger complexes with metals than inorganic ligands (Johnson and others, 1989). Organic ligands include: (1) synthetic compounds from wastes, such as amines, pyridines, phenols, and other organic bases and weak acids, and (2) natural organic materials, primarily humid materials (Schnitzer, 1969; Hayes and Swift, 1978; Stevenson, 1982, 1985; Johnson and others, 1989). Humic materials have complex structures, and their complexation behavior is difficult to be predicted (Perdue and Lytle, 1983; Sposito,1984; Perdue, 1985; Dzombak and others, 1986; Fish and others, 1986).

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Generally, humic materials are found in significant concentration only in shallow aquifers. In these aquifers, however, they may be the primary influence on the behavior of metals (Thurman, 1985).

Equilibrium among reactants and complexes for a given reaction is predicted by an equilibrium (or "stability") constant, K, which defines a mass-law relationship among the species (Johnson and others, 1989). For given total ion concentrations (measured analytically), stability constants can be used to predict the concentration of all possible species (Martell and Smith, 1974, 1977; Smith and Martell, 1975).

Because complexes decrease the amount of free ions in solution, less metal may sorb onto aquifer solid materials or participate in precipitation reactions (Johnson and others, 1989). The metal is more soluble because it is primarily bound up in the soluble complex. Research has demonstrated that a metal undergoing complexation may be less toxic to aquifer microorganisms (Reuter and others, 1979).

Sorption and Surface Chemistry. Surface sorption, in many cases, is the most important process affecting toxic metal transport in the subsurface (Johnson and others, 1989). Changes in metal concentration, as well as pH, can have a significant effect on the extent of sorption (figure 4.7).

Approaches to predicting behavior of metal ions based on sorption processes include using isotherms (indicating that data were collected at a fixed temperature) to graphically and mathematically represent sorption data (Johnson and others, 1989). Two types of isotherms are commonly used: the Freundlich isotherm and the Langmuir isotherm (figure 4.8). The Freundlich isotherm is empirical, and sorbed (S) and aqueous (C) concentration data are fitted by adjusting two parameters (K and a). The Langmuir isotherm is based on the theory of surface complexation, using a parameter corresponding to the maximum amount that can be sorbed and the partition coefficient, K (Morel, 1983).

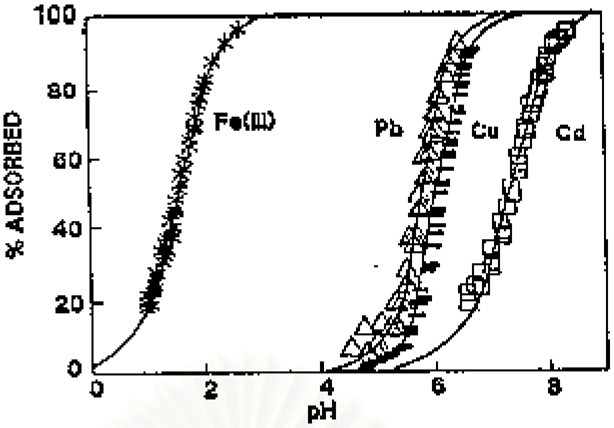

Figure 4.7 Adsorption of Metal Ions on Amorphous Silica as a Function of pH (adapted from Schindler and others, 1976, by Johnson and others, 1989)

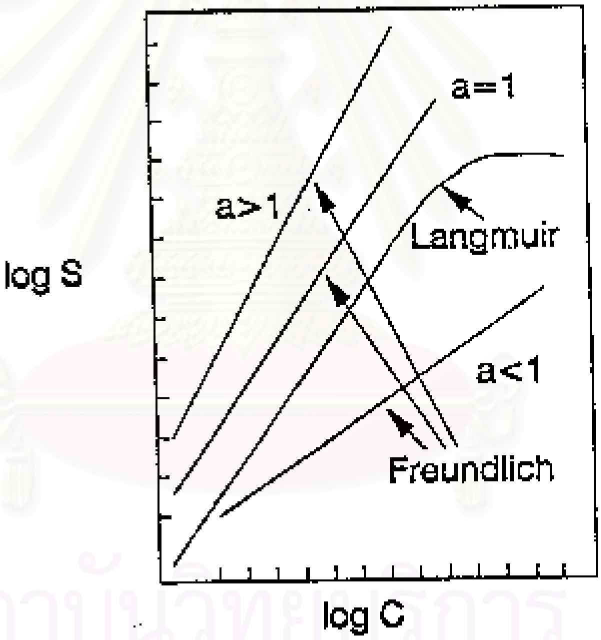

Figure 4.8. Schematic Representation of Freundlich and Langmuir Isotherm Shapes for Batch Equilibrium Tests (Johnson and others, 1989)

Another method to describe sorption is to use surface complexation models that represent sorption as ions binding to specific chemical functional groups on a reactive surface (Johnson and others, 1989). All surface sites may be identical or may be grouped into different classes of sites (Benjamin and Leckie, 1981). Each type of site has a set of specific sorbing constants, one for each sorbing compound. Electrostatic forces at the surface also contribute to the overall sorption constant (Davis and others, 1978). Binding of ions to the surface is calculated from constants using mass-law equations similar to those used to calculate complex formation (Schindler and others, 1976; Stumm and others, 1976; Dzombak and Morel, 1986). However, the parameters used in surface complexation models are data-fitting parameters, which fit a specified set of data to a particular model, but have no thermodynamic meaning and no generality beyond the calibrating data set (Westall and others, 1980).

Ion-Exchange Reactions. Ion-exchange reactions are similar to sorption. However, sorption is coordination bonding of metals (or anions) to specific surface sites and is considered to be two-dimensional, while an ion exchanger is a three-dimensional, porous matrix containing fixed charges (Helfferich, 1962; Johnson and others, 1989). Ions are held by electrostatic forces rather than by coordination bonding. Ion-exchange "selectivity coefficients" are empirical and vary with the amount of ion present (Reichenburg, 1966). Ion exchange is used to describe the binding of alkali metals, alkaline earths, and some anions to clays and humic materials (Helfferich, 1962; Sposito, 1984). Knowledge of ion exchange is used to understand the behavior of major natural ions in aquifers and also is useful for understanding behavior of contaminant ions at low levels. In addition, ion exchange models are used to represent competition among metals for surface binding (Sposito, 1984).

Redox Chemistry. Reduction-oxidation (redox) reactions involve a change in the oxidation state of elements (Johnson and others, 1989). The amount of change is determined by the number of electrons transferred during the reaction (Stumm and Morgan, 1981). The oxidation status of an element can be important in determining the potential for transport of that element. For example, in slightly acidic to alkaline environments, Fe (III) precipitates as a highly sorptive phase (ferric hydroxide), while Fe (II) is soluble and does not retain other metals. The reduction of Fe (III) to Fe (II) releases not only Fe^{+2} to the water, but also other contaminants sorbed to the ferric hydroxide surfaces (Evans and others, 1983; Sholkovitz, 1985).

Chromium (Cr) (VI) is a toxic, relatively mobile anion, while Cr (III) is immobile, relatively insoluble, and strongly sorbs to surfaces. Selenate (Se) (VI) is mobile but less toxic, while selenite Se(IV) is more toxic but less mobile (Johnson and others, 1989).

The redox state of an aquifer is usually closely related to microbial activity and the type of substrates available to the microorganisms (Johnson and others, 1989). As organic contaminants are oxidized in an aquifer, oxygen is depleted and chemically reducing (anaerobic) conditions form. The redox reactions that occur depend on the dominant electron potential, which is defined by the primary redox-active species. The combination of Fe(II)/Fe(III) defines a narrow range of electron potentials, while (S) (sulfur)(+IV)/S(-II) defines a broader range. Pairs of chemical species are called redox couples.

After oxygen is depleted from ground water, the most easily reduced materials begin to react and, along with the reduced product, determine the dominant potential. After that material is reduced, the next most easily reduced material begins to react. These series of reactions continue, usually catalyzed by microorganisms. An aquifer may be described as "mildly reducing" or "strongly reducing," depending on where it is in the chemical series (Stumm and Morgan, 1981).

The electron potential of water may be measured in volts, as Eh, or expressed by the "pe," which is the negative logarithm of the electron activity in the water (Johnson and others, 1989). A set of redox reactions is often summarized on a pH-pe (or pH-Eh) diagram, which shows the predominant redox species at any specified pH and pe (or Eh). In this theoretical approach, only one redox couple should define the redox potential of the system at equilibrium. However, in an aquifer, many redox couples not in equilibrium can be observed simultaneously (Lindberg and Runnels, 1984). Therefore, redox behavior of chemicals in aquifers is difficult to predict. However, the redox status of an aquifer is important because of its effects on the mobility of elements and the potential effects on biodegradation of organic contaminants. Anaerobic (reducing) conditions are not favorable for hydrocarbon degradation, but reducing conditions favor dehalogenation of chlorinated and other halogenated compounds (Johnson and others, 1989).

4.4 Modeling Transport and Fate of Contaminants in an Aquifer

Models are simplified representations of real-world processes and events, and their creation and use require many judgments based on observation of simulations of specific natural processes. Models may be used to simulate the response of specific problems to a variety of possible solutions (Keely, 1989b).

Physical models, including sand-filled tanks used to simulate aquifers and laboratory columns used to study contaminant flow through aquifer materials, often are used to obtain information on contaminant movement (Keely, 1989b). Analog models also are physically based, but are only similar to actual processes. An example is the electric analog model, where capacitors and resistors are used to replicate the effects of the rate of water release from storage in aquifers. The main disadvantage of physical models is the time and effort required generating a meaningful amount of data.

Mathematical models are non-physical and rely on quantification of relationships between specific parameters and variables to simulate the effects of natural processes (Keely, 1989b, Weaver and others, 1989). Because mathematical models are abstract, they often do not provide an intuitive knowledge of real world situations. However, mathematical models can provide insights into the functional dependencies between causes and effects in an actual aquifer. Large amounts of data can be generated quickly, and experimental modifications made easily, making possible for many situations to be studied in detail for a given problem.

4.4.1 Use and Categories of Mathematical Models

The application of mathematical models is subject to error in real-world situations when appropriate field determinations of natural process parameters are lacking. This source of error is not addressed adequately by sensitivity analyses or by the application of stochastic techniques for estimating uncertainty. The high degree of hydrogeological, chemical, and microbiological complexity typically present in field situations requires the use of site-specific characterization of the influences of various natural processes by detailed field and laboratory investigations (Keely, 1989b).

Mathematical models have been categorized by their technical bases and capabilities as: (1) parameter identification models; (2) prediction models; (3) resource management models; and (4) data manipulation codes. (Bachmat and others, 1978; van der Heidje and others, 1985).

Parameter identification models are used to estimate aquifer coefficients that determine fluid flow and contaminant transport characteristics (e.g., annual recharge, coefficients of permeability and storage, and dispersivity (Shelton, 1982; Guven and others, 1984; Puri, 1984; Khan, 1986a, b; Strecker and Chu, 1986)). Prediction models are the most numerous type because they are the primary tools used for testing hypotheses (Mercer and Faust, 1981; Anderson and others, 1984; Krabbenhoft and Anderson, 1986).

Resource management models are combinations of predictive models, constraining functions (e.g., total pumpage allowed), and optimization routines for objective functions (e.g., scheduling well field operations for minimum cost or minimum drawdown/pumping lift). Few of these types of models are developed well enough or supported to the degree that they are useful (van der Heidje,1984a and b; van der Heidje and others, 1985).

Data manipulations codes are used to simplify data entry to other kinds of models and facilitate the productions of graphic displays of model outputs (van der Heidje and Srinivasan, 1983; Srinivasan, 1984; Moses and Herman, 1986).

4.4.2 Mathematical model application in groundwater contamination analysis

Ready-made program used in the model

In leachate contamination analysis into groundwater sources by application of mathematics model, Visual MODFLOW Model which is the main program in calculation of the groundwater flow and has been used in association with hydrological system. Other than MODFLOW Program as used in calculation of groundwater velocity, there is post processing program as used for illustration of the strongest hydraulic gradient direction of the steady state simulation which will be useful for application in the study of distribution of the contaminant in the groundwater. That is MODPATH Program, which is inside the Visual MODFLOW Program.

Visual MODFLOW program as used in calculation of contamination movement in water which could be jointly used with MODFLOW Program also combines another program of analysis and calculation of contaminate distribution and chemical reactions of some substance with the MODFLOW Program based on calculation of water velocity. The program that has been taken to join with calculation of contaminate distribution is called MT3D (Mass Transport Three-Dimension Model, Zheng; 1996)

Simulation of movement and distribution of leachate contamination into groundwater sources.

The most significant factor which sets out the movement and distribution of contamination in groundwater is the groundwater flow. Therefore, the groundwater flow patterns in the studied areas have been simulated and then movement and distribution patterns of contamination from leachate by application of Visual MODFLOW Program. An example of procedures of groundwater flow model application in this project is shown in figure 4.9

Assessment of leachate Contamination by Mathematical Models

Selected mathematical models for the simulation and assessment of leachate contamination in this study comprise Visual MODFLOW and Visual MT3D96 models

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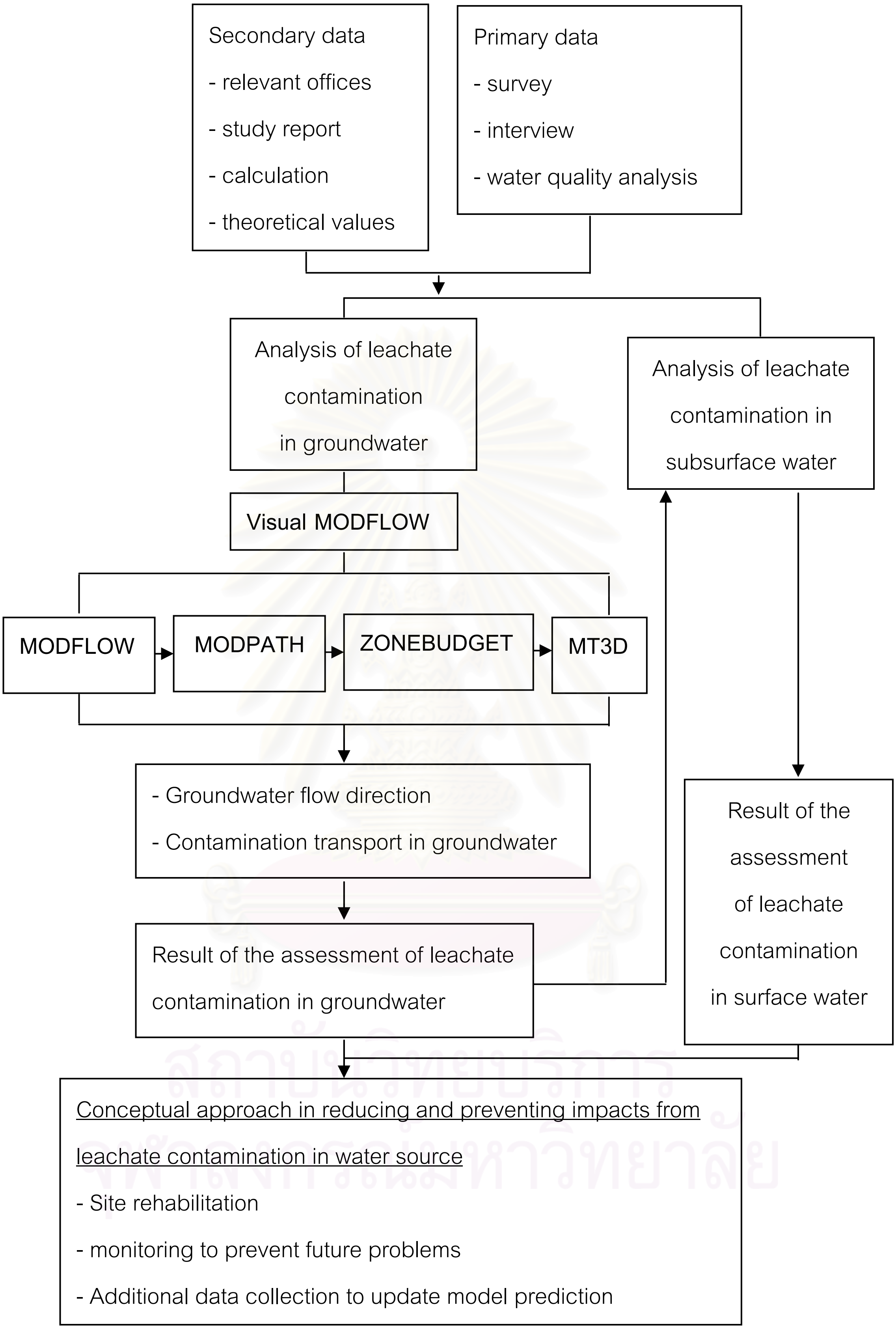

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Figure 4.9 Procedure for the study and analysis of leachate contamination in water resources.

Visual MODFLOW Model

The MODFLOW Model is a three-dimensional groundwater flow model that is used in estimating groundwater flows in multi-layers either of unconfined or confined subsurface conditions depending on their corresponding hydrologic characteristics. Results from the model will show the hydraulic heads and ground water flow direction as well as the velocity and flow distance at specified time intervals.

Input data for the MODFLOW model run comprise the results of the HELP Model, the soil borings and geotechnical testing for each disposal site particularly the hydraulic conductivity of the geotechnical testing for each disposal site especially that of the underlying soil layer next to the waste layer, and the groundwater level at various monitoring wells as well as the observed water levels of surrounding surface water. The obtained groundwater elevation data of each disposal site will be used to determine the groundwater flow direction and to assess the possible impact of lechate contamination to the nearby drinking water well within the 2–kilometer radius distance of the site. The observed ground water table data will be input to the MODFLOW Model so as to compare with the data obtained from the model output and further performing the model calibration accordingly.

Visual MT3D96 Model

The MT3D96 Model is a modular three-dimensional groundwater transport model which can be used to simulate the advection, dispersion and chemical reaction of the solutes in groundwater environments. The model can be run along with the ground water flow model like MODFLOW Model with the assumption that variations of the solute concentrations do not affect the groundwater flows, and it can estimate a variety of contaminant migration in ground water.

From the analytical reports of the leachate samples at the selected disposal sites, it is found that the lecahate were largely contaminated with the heavy metals such as mercury, lead, chromium, nickel and cadmium which, when contaminated

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in ground water source for human consumption, would create the health hazard to humans. As the groundwater quality standard for drinking purpose has set up the maximum allowable limits of the heavy metals, this study therefore selected specific heavy metals found at relativity high concentrations in the leachate and groundwater samples. Emphasis was placed on the highest ration of the heavy metal concentration to the corresponding standard value, and was input as the contaminant source data to the model. Meanwhile the observed groundwater qualities of the two downgrading monitoring wells of each disposal site was used to calibrate the model run outputs when the site service life was recorded. Results of the MT3D96 Model runs would display the contour lines of selected contaminant concentrations at a variety of migration distance and time intervals such as 10, 20, 50 or 100 years from the initial stage of lechate leakage through the groundwater

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CHAPTER V

METHOD OF STUDY

The methods performed for the present study are collection and study of the basic data, performing primary survey, field investigation and water sample collection, laboratory analysis of water samples, interpretation of the result and conclusion respectively are as shown in figure 5.1 and mentioned in detail further on.

5.1 Collection and study the basic data

The basic data of the study area were collected and studied in order to plan the sampling pattern. Three type of data framework are:

5.1.1 Physical framework consists of

-Topographic maps, scale 1:50,000, Sheet 5036 I and 5037 II

-Geological map, scale 1:250,000 prepared by Department of Mineral Resource (1998)

-Hydrogeological map, scale 1:250,000 prepared by Department of Mineral Resource (1998) and

-Soil map series no.8, scale 1:100,000 prepared by Soil Survey Division, Land Development Department (1972)

5.1.2 Hydrological framework consists of the data which vary with time such as meteorological records from Meteorological Department, groundwater data from Groundwater Division, Department of Mineral Resources (DMR) and private sectors such as Layne (Thailand) Ltd., and surface water data from Royal Irrigation Department, etc.

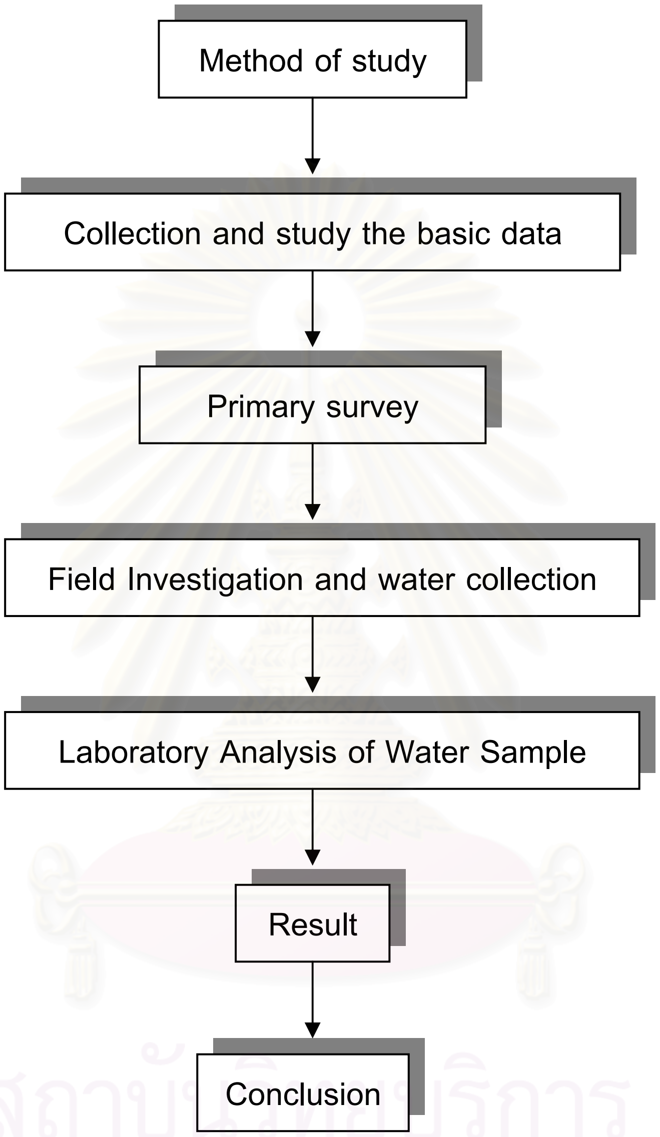

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Figure 5.1 Method of Study

5.1.3 The development framework include the data on land use, existing report, collection of system management refuse waste, population, solid waste generation quantity, solid waste collection quantity, solid waste disposal system, transportation and disposal method, solid waste management situation in the study area and solid waste components were explained in the previous Chapter 3.

5.2 Primary survey

The stages of survey begin with a general investigation of the disposal site, especially on the hydrogeological characteristics, soil characteristics, land use around the disposal site and water resources in the surrounding area. The coordinate positioning of disposal sites was derived using the global positioning system (GPS) and plotted on the base map. The existing landuse map of the study area was also prepared

5.3 Field Investigation and water collection

5.3.1 Preparation for the field work.

Before the field survey, the background information had been studied and the materials and equipments should be acquired as following:

- Base maps : the topographic maps of 1 : 50,000 scale, map sheets 5036 I and 5037 II for plotting down the sample locations,
- Global Positioning System : GARMIN GPS 12 was used for locating the positions where the water samples were collected,
- Record sheet, to record the surveying data,
- pH meter : HANNA HI 8424,
- Conductivity meter : HACH SensION 5,
- DO meter : HANNA HI 9142,
- Electric drop line for measurement of water level,
- Measuring tape, 2 meters length,
- Plastic bottles: 250 cc, 500 cc and 1000 cc ,
- Bailer for water samples collection in the opened shallow wells,
- NaOH, HNO_3 and H_2SO_4 for water sample preservation,

- 200 cc plastic beakers for field measurement of pH, conductivity and temperature,
- Deionized water for washing equipments.

5.3.2 Field measurement and Water Sample Collection

5.3.2.1 Groups of Water Sample

Four groups of water sample namely leachate, surface water, shallow subsurface water and deep subsurface water, were randomly collected at the disposal sites and its vicinity in order to determine the existing water qualities.

1) Leachate sample was collected from the leachate impounding pond just north of the disposal site within the site property boundary.

2) Surface water was sampled from the adjacent surface water sources within two kilometers radius of the disposal site, such as ponds, pits and flowing canals. In the flowing canals, the water samples were collected from both upstream and downstream from the disposal site. Elsewhere only one sample was collected from a still water source. This is according to the standard method for the community waste management of the Pollution control department (1999).

3) Shallow subsurface water samples were taken from installed monitoring wells drilled by Pollution Control Department at the disposal site and 1 more sample from outside the disposal site. Prior the sample collection, decontamination practice of all sampling equipment must be warranted.

4) Deep subsurface water samples were collected from deep wells also within a two-kilometer radius of the disposal site. The wells are those owned by the governmental agencies such as Department of Mineral Resources, Public Works Department, the Office of Accelerated Rural Development and Royal Irrigation Department.

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5.3.2.2 Period for collecting water samples

Water samples were generally collected 5 times, except the leachate, which was collected only once during a period of 12 months, on August 18, 2001, October 28, 2001, January 27, 2002, March 27, 2002 and July 27, 2002. This is to study the water quality, which might be changed annually. In the first visit, the water samples were collected from 4 shallow subsurface water locations, 3 deep well locations and 7 surface water locations. In the second and third visits, the collected water samples were from 4 shallow subsurface water locations, 5 deep water well locations and 7 surface water locations. In the fourth collection, the water samples were from 3 shallow subsurface water locations, 9 deep well water locations and 7 of surface water locations, as one of the shallow subsurface well, NL 2, was damaged during a ground improvement process while the number of deep well samples were increased in order to cover the study area more thriughtoutly. In the last fieldwork the collected water samples were thus from 3 shallow subsurface water locations, 9 deep well water locations, and 7 surface water locations with an additional surface sample collected from the leachate impounding pond. The total number of samples was summarized in table 5.1

Table 5.1 The total number of samples

	Date	Subsurface water		Surface water	Leachate
		Shallow well	Deep well		
1	August 18, 2001	4	3	7	-
2	October 28, 2001	4	5	7	-
3	January 27, 2002	4	5	7	-
4	March 27, 2002	3	9	7	-
5	July 27, 2002	3	9	7	1

The locations of the collected water sample are shown in figures 6.1, 6.2, 6.3 and 6.4. The position is measured from global position system (GPS) as shown in Table 6.1, 6.2 and 6.3

5.3.2.3 Field Data collection, field measurement and water collection

The procedure employed in each water sample cillection is as following.

- Before the field operation, the basic data such as water level, and depth of eroded casing or screen, including other basic data, were noted and compared with the previously collected data.
- The coordinate of locations of water sample was done by using GPS (Global Positioning System) and plotting in the base map.
- Measuring the static water level was determined from monitoring wells, to define the direction of the water movement using 3 static water level from monitoring wells.
- Measurment of the parameters as temperature, pH, electrical conductivity , TDS and DO were done at the sampling sites and well head analysis was performed at the monitoring of deep wells.
- Water samples were them collected for laboratory analysis.

The water samples were collected and preserved differently, according to the water sample groups and parameters to be analyzed as summarized in Table 5.2.The shallow subsurface water samples were collected by using a bailer and were filtered before preserving and collecting for the laboratory analysis. Leachate water sample was also filtered before preservation and collection.

Water samples were kept in the plastic bottles, which were rinsed by the respective water samples themselves before receiving the samples..

Table 5.2 Collection and preservation of water samples

Plastic Bottle	Preservation	Volume (ml)	Determination
1	Add 3 ml of 1+1 HNO_3 to pH <2	1000	Total Hardness, Hg, Fe, Ni, Zn, As, Mg, Ca, Na, K, Cu, Cr, Cd, Pb and Mn
2	Refrigerate; add 4 drops 2N zinc acetate/100 ml ; add 4 drops 6 N of NaOH to pH >9	100	Sulfide
3	Cool, 4^{O} C, add 8 drops H_2SO_4 to pH<2	250	Ammonia_and Nitrate_ Nitrogen
4	Add 4 drops of NaOH to pH >9	100	CN^-

Randomly grabbed sampling of all water samples were employed for the entire work. Preservation of the collected samples and the analytical methods of selected parameters are in accordance to the APHA' s Standard Method for the Examination of Water and Wastewater, 18th edition, 1992 (Table 5.3).

5.4 Laboratory Analysis of Water Samples

The collected water samples were analyzed within time limit of each parameter (table 5.3). The instruments used for laboratory analysis are;

- UV-VIS Spectrophotometer : Milton Roys, Genesys 10
- Atomic Absorption Spectrometer (AAS) : Perkin Elmer AA300 and FIAS 400
- Advanced Water Quality Laboratory : HACH, DREL/2010

The water analysis was done in geochemical laboratory of Geology Department, Faculty of Science, Chulalongkorn University.

The conditions for the determination by Atomic Absorption Spectrometry are listed in Table 5.4

Table 5.3 Conclusion of sample collection, preservation and method of analysis

Parameter	Container	Preservation	Storage	Method of analysis
1. Static water level	-	-	-	Water Level Meter
2. pH	-	-	-	pH meter
3. Conductivity	-	-	-	Conductivity meter
4. Temperature	-	-	-	Conductivity meter
5. DO	-	-	-	DO meter
6. TDS	-	-	-	Conductivity meter
7. Total Hardness	Plastic (PE)	Add HNO3 to pH <2	10 day	EDTA Titrimetric Method
8.Sulfide	Plastic (PE)	Refrigerate; add 4 drops 2N zinc acetate/100 ml; add NaOH to pH >9	3 day	Methylene Blue Method
9.Ammonia Nitrogen	Plastic (PE)	Cool, 4^{O} C, H_2SO_4 to pH<2	4 day	Nessler Method
10.Nitrate_Nitrite	Plastic (PE)	Cool, 4^{O} C, H_2SO_4 to pH<2	4 day	Cadmium Reduction Method
11.Mercury (Hg)	Plastic (PE)	Add HNO_3 to pH <2	5 – 6 day	AAS-HG
12.Total Iron (Fe)	Plastic (PE)	Add HNO_3 to pH <2	9 day	FerroVer Method
13.Nickel (Ni)	Plastic (PE)	Add HNO_3 to pH <2	10 – 11 day	AAS
14.Zinc (Zn)	Plastic (PE)	Add HNO_3 to pH <2	12 - 13 day	AAS
15.Arsenic (As)	Plastic (PE)	Add HNO_3 to pH <2	5 – 6 day	AAS-HG
16. Magnesium (Mg)	Plastic (PE)	Add HNO_3 to pH <2	17 – 20 day	AAS
17. Calcium(Ca)	Plastic (PE)	Add HNO_3 to pH <2	17 – 20 day	AAS
18. Sodium (Na)	Plastic (PE)	Add HNO_3 to pH <2	17 – 20 day	AAS
19. Potassium (K)	Plastic (PE)	Add HNO_3 to pH <2	17 – 20 day	AAS
20. Copper (Cu)	Plastic (PE)	Add HNO_3 to pH <2	12 – 13 day	AAS
21. Cyanide (CN^-)	Plastic (PE)	Add NaOH to pH >9	2 day	Pyridine-Pyrazalone method
22.Chromium (Cr)	Plastic (PE)	Add HNO_3 to pH <2	12 – 13 day	AAS
23.Cadmium (Cd)	Plastic (PE)	Add HNO_3 to pH <2	10 – 11 day	AAS
24.Lead (Pb)	Plastic (PE)	Add HNO_3 to pH <2	12 - 13 day	AAS
25.Maganess (Mn)	Plastic (PE)	Add HNO_3 to pH <2	12 – 13 day	AAS

Source : Standard methods for the examination of water and wastewater , 1992 , edited by Arnold E. Greenberg and Lenore S. Clesceri,Andrew D. Eaton, 18 th –edition

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Table 5.4 The conditions for the determination by Atomic Absorption Spectrometer

Element	Technique	Flame gases or gas	λ (nm)
Hg	ASS-HG	Ar	253.7
NI	FAAS	A-Ac	232.0
Pb	FAAS	A-Ac	283.3
Zn	FAAS	A-Ac	213.9
Mn	FAAS	A-Ac	279.5
As	AAS-HG	Ar	193.7
Cd	FAAS	A-Ac	228.8
Mg	FAAS	A-Ac	285.2
Ca	FAAS	A-Ac	422.7
Na	FAAS	A-Ac	589.0
K	FAAS	A-Ac	766.5
Cu	FAAS	A-Ac	324.8
Cr	FAAS	A-Ac	357.9

A-Ac = Air-Acetylene
Ar = Argan

5.5 Modflow Plot

The modflow plot was prepared by considering 3 factor as follows:

1) Model Grid

The area was discretized into rectangular grid blocks (25 grid blocks in east-west and 30 grid blocks in north-south direction) and the depth was sliced into 4 layers. The grid sizes of the model are 5000 m. and 6000 m. in the X and Y coordinates respectively. Therefor, the model represents a groundwater flow domain of 3,000 grid blocks (25 x 30 x 4)

2) Boundary Condition

Due to the complexity of the natural subsurface regime and limited hydrogeolgical data, it is necessary to consider the model limitations and assign proper boundary conditions of the flow domain. In this case, the canals were used as the boundary limit in the north, east, south, and west direction and clay layer underlies Bangkok aquifer in the Z-direction.

3) Hydrogeologic Parameter

The Modflow program requires the following hydrogelogic parameters.

- Top and bottom elevation of each layers
- Type of each layers
- Porosity
- Specific Storage
- Hydraulic conductivity in three directions
- Recharge Rate
- Static Water Level (table 6.4)

The data used (Table 5.5) are from Pollution Control Department (1998) Consultant of Technology (1998) Ramnarong (1973) and a practical guide to groundwater and solute transport model of Spitz and Moreno's (1996)

Table 5.5 Data Inputting for The Model

Layer	Depth (m)	K (cm/sec)	Specific Storage	Effective porosity	Source
1	0 – 10	6.14×10^{-5}	6.72×10^{-2}	0.03	PCD, COT and Spitz and Moreno, 1996
2	10 – 12	6.14×10^{-5}	6.72×10^{-2}	0.03	PCD, COT and Spitz and Moreno, 1996
3	12 –15	6.14×10^{-5}	6.72×10^{-2}	0.03	PCD, COT and Spitz and Moreno, 1996
4	15 – 80	6.8×10^{-2}	1.538×10^{-6}	0.043	Ramnarong, 1973 Spitz and Moreno, 1996
5	80 - 90	6.14×10^{-5}	1.538×10^{-6}	0.01	Ramnarong, 1973 Spitz and Moreno, 1996

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CHAPTER VI

RESULTS

6.1 Location of Sampling

The water samples were collected from two main sources, which comprising surface and subsurface water sources as shown in the figure 6.1. The surface water samples were collected from the water sources around the study area such as canals, borrow pit and pond. The subsurface water samples are from shallow and deep water wells. The depth of the shallow wells is less than 13.5 meters, whereas the deep wells are more than 200 meters deep. The water of the deep wells is from Nonthaburi aquifer and Sam Khok aquifer, which is the principal water supply for the Sainoi community. The water samples were collected cover the study area and extend approximately 2 Kilometers further from the disposal site. The positions of water sampling were located by Global Position System (GPS) and plotted on the basemap, scale 1:50,000.

The localities of the sampling site including description of the wells are described below:

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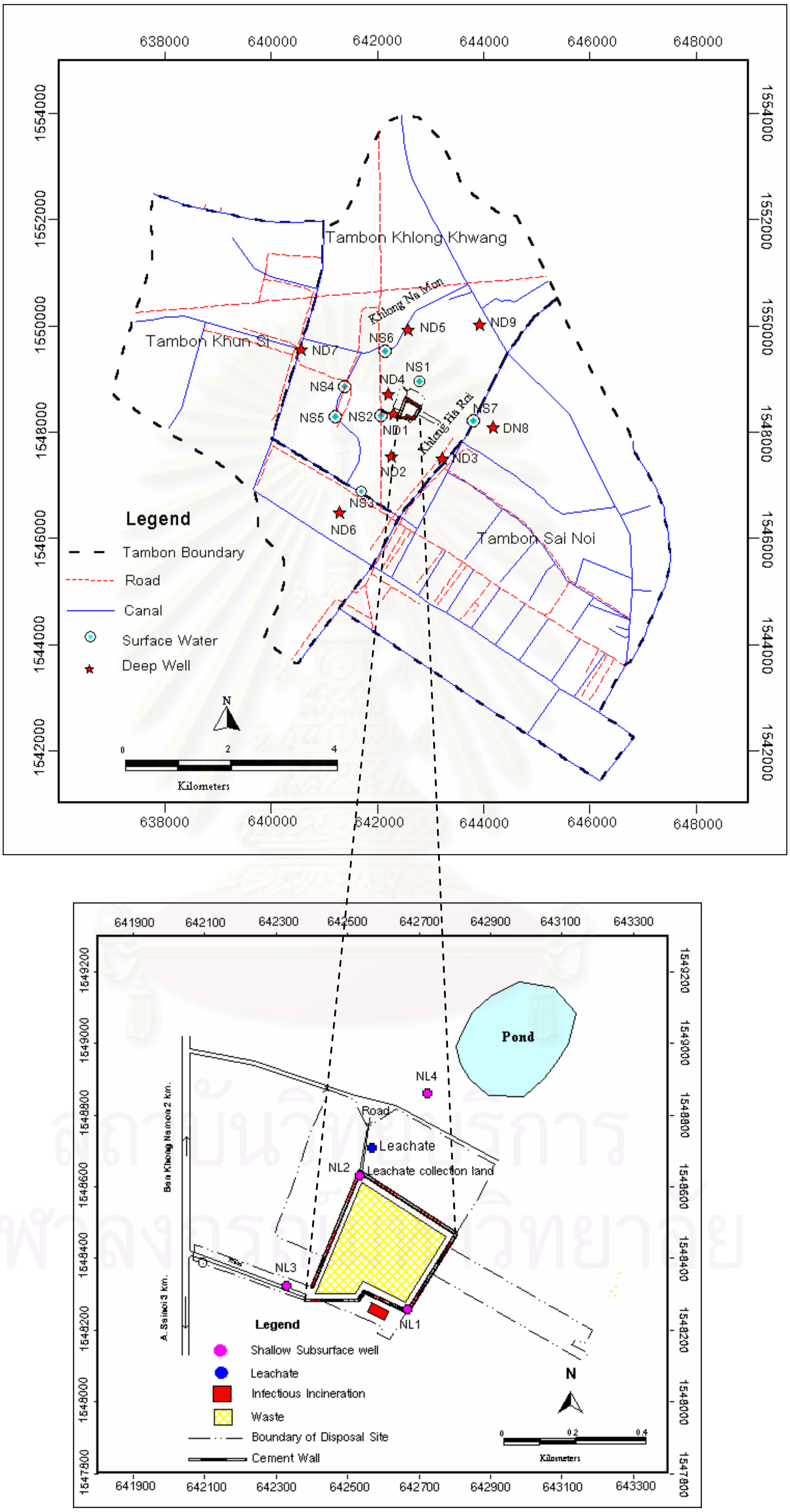

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Figure 6.1 Locations of water sampling

6.1.1 Subsurface Water

6.1.1.1 Shallow Well

The localities of the shallow water sampling sites including description are shown in Table 6.1 and Figure 6.2

Table 6.1 The position of subsurface water sampling from shallow well

Location No.	UTM Grid		Depth (m)	Description
	Easting	Northing		
NL1	642677	1548250	13.30	Monitoring well locating north and in the disposal area, drilled by the Pollution Control Department for observation.
NL2	642538	1548630	13.30	Monitoring well locating south and in the disposal site area, drilled by the Pollution Control Department for observation.
NL3	642335	1548323	13.30	Monitoring well locating southeastern and in the disposal site area, drilled by the Pollution Control Department for observation.
NL4	642728	1548859	>13	Dug well about 300m northward from the disposal site, drilled by the local administration. No details of this well, only that the unconfined water table could normally be observed

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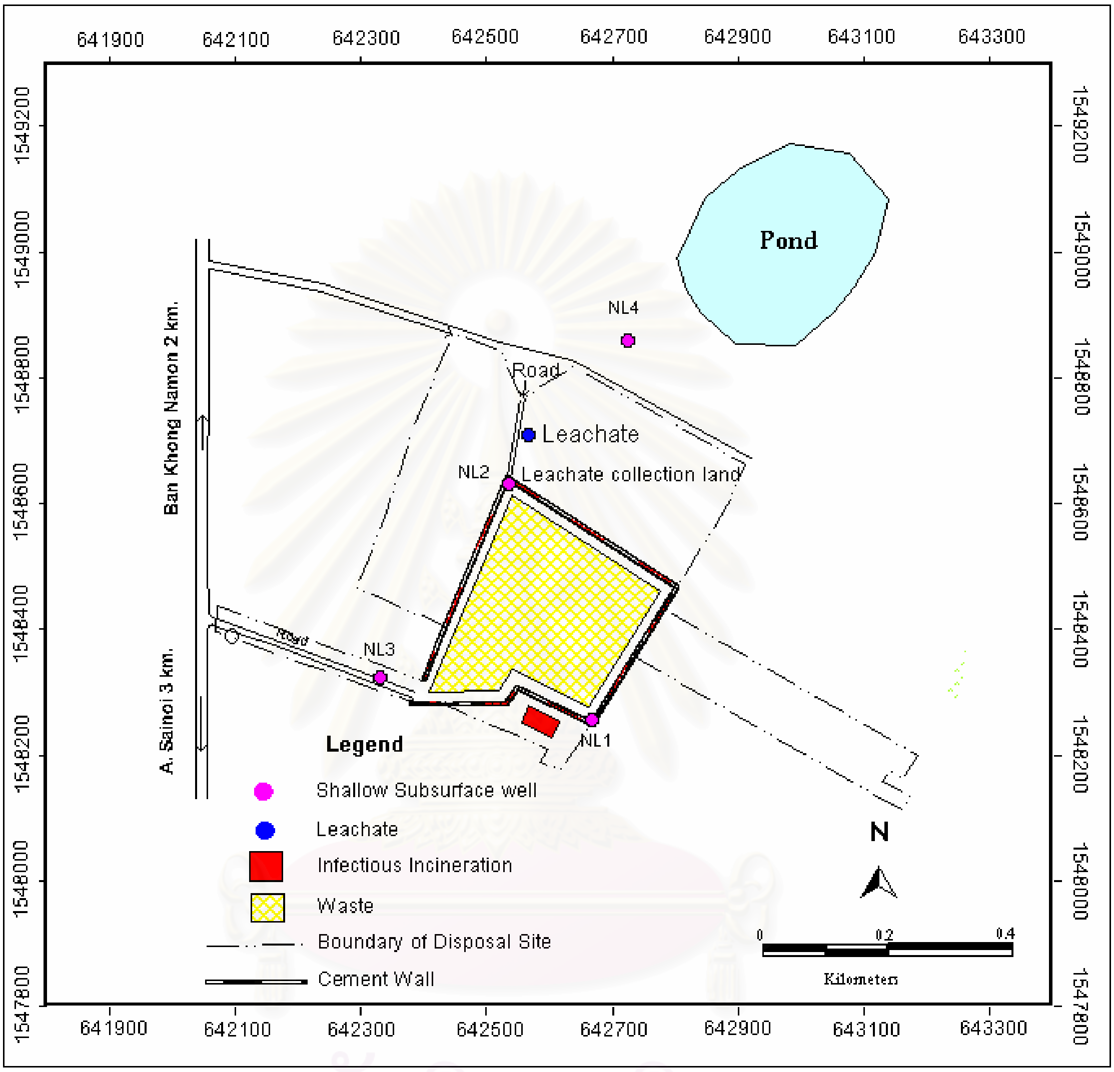

Figure 6.2 Locations of Shallow Subsurface Water Collection

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6.1.1.2 Deep well

The water samples were collected from nine deep wells designated as ND1 to ND9. The depth of the wells ranges from 200 to 280 meters, and groundwater is from either the Nonthaburi aquifer and Sam Khok aquifer.

The localities and description of the sampling sites are presented in table 6.2 and figure 6.3.

Table 6.2 The position of subsurface water sampling from deep well

Location	UTM Grid		Depth	Description
No	Easting	Northing	(m)	
ND1	642293	1548346	250	It is located 50 meters southwestern of the disposal site, drilled by Provincial Administration office of Sainoi
ND2	642264	1547545	200	It is located 1.0 kilometers southward of the disposal site, drilled by Sainoi community.
ND3	643216	1547518	252	It is located 250 meters northwestern of the disposal site, drilled by Sinphet community.
ND4	642202	1548732	200	It is located 1.0 kilometers southeastern of the disposal site, drilled by Department of Mineral Resource.
ND5	642569	1549943	200	It is located 1.8 kilometers northward of the disposal site, drilled by Accelerated Rural Development Department.

Table 6.2 The position of subsurface water sampling from deep well (Cont.)

Location No	UTM Grid		Depth (m)	Description
	Easting	Northing		
ND6	641281	1546489	252	It is located 2.0 kilometers southwestern of the disposal site, drilled by Provincial Administration Office Of Nonthaburi.
ND7	640555	1549557	276	It is located 2.0 kilometers northwestern of the disposal site, drilled by Public Work Department.
ND8	644165	1548091	255	It is located 1.8 kilometers eastward of the disposal site, drilled by Provincial Administration Office of Sainoi.
ND9	643927	1550035	250	It is located 2 kilometers northeastern of the disposal site, drilled by Provincial Administration office of Nonthaburi.

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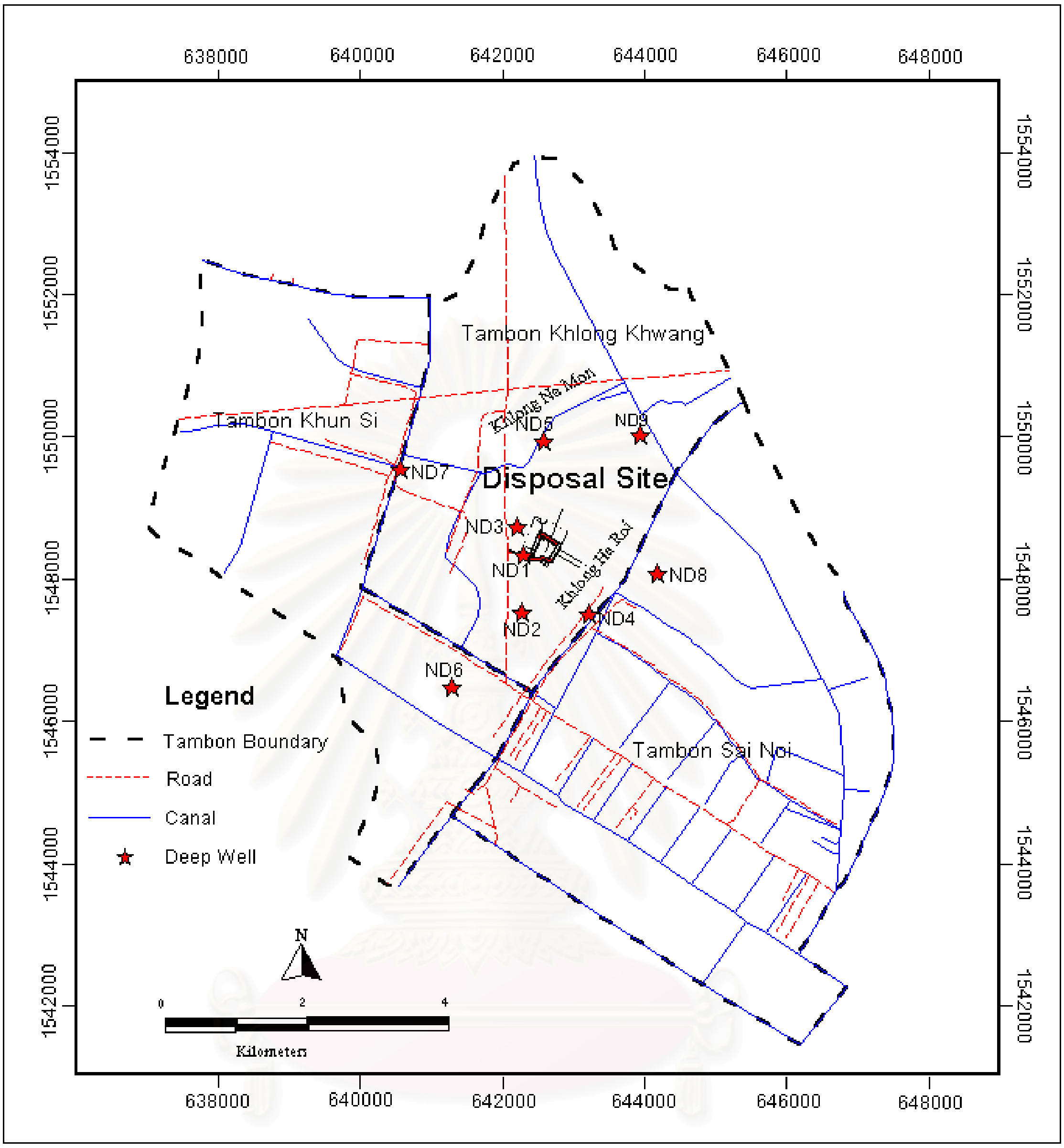

Figure 6.3 Locations of Deep Well Collection

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6.1.2 Surface Water

The surface water sampling was collected from seven locations around project area.

The localities and description of the sampling sites are presented in table 6.3 and figure 6.4

Table 6.3 The position of surface water sampling

Location No	UTM Grid		Depth (m)	Description
	Easting	Northing		
NS1	642779	1548951	16	Borrow pit, 16 m deep located 250 meters northward of the disposal site.
NS2	642072	1548309	4	Pond, located 250 meters southwestern of the disposal site.
NS3	641697	1546894	2	Khlong Na Mon 1.8 kilometers downstream from the disposal site.
NS4	641386	1548868	2	Khlong Na Mon 1 kilometer downstream from the disposal site.
NS5	641198	1548287	2	Khlong Na Mon 1 kilometer downstream from the disposal site.
NS6	642139	1549515	2	Khlong Na Mon 1.8 kilometers upstream from the disposal site.
NS7	643246	1547511	2	Khlong Ha Roi 1.8 kilometers upstream from the disposal site.

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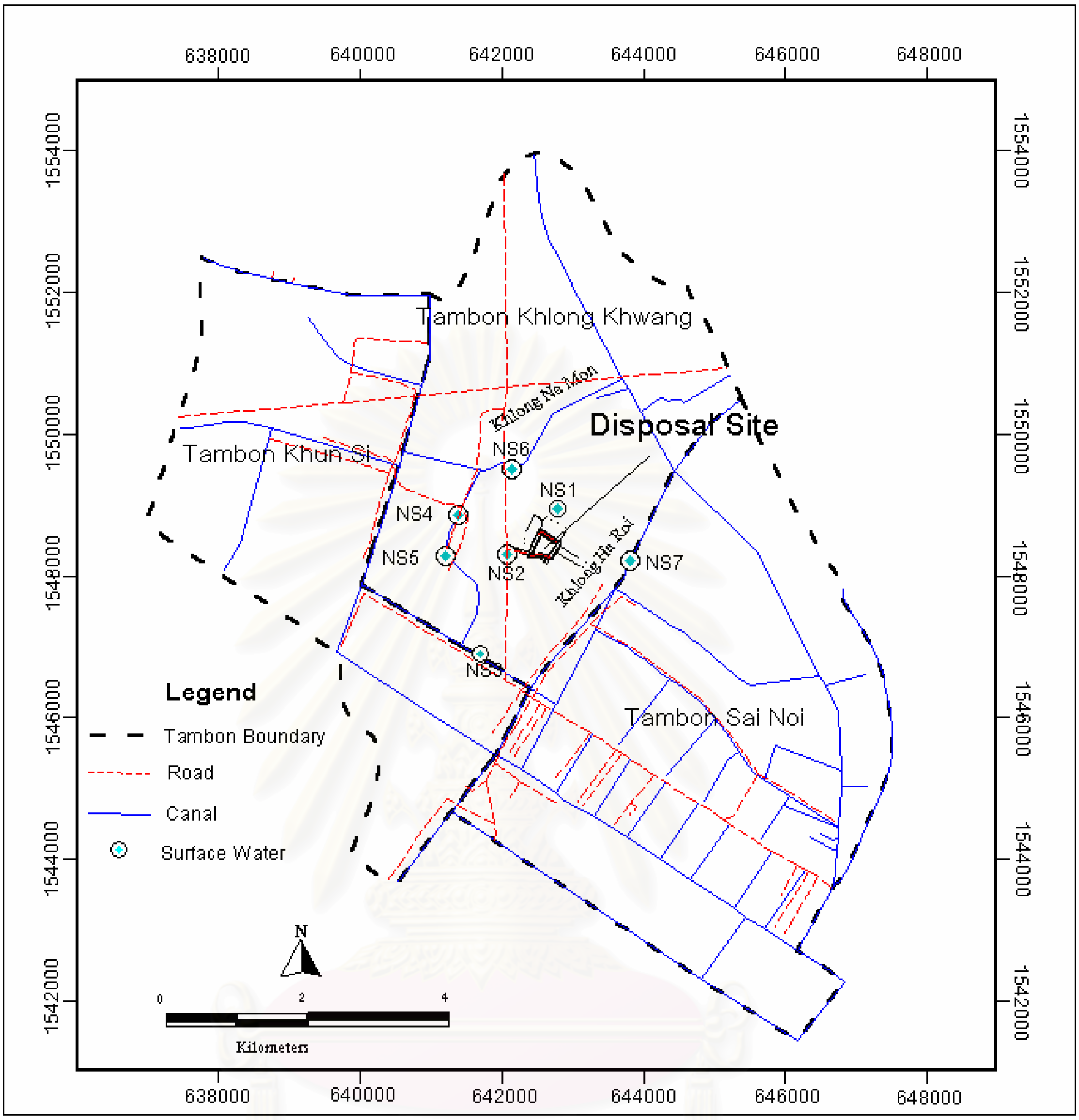

Figure 6.4 Locations of surface water sampling.

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6.2 Direction of shallow subsurface flow

The static water level measured in the monitoring well (Table 6.4) to define the direction of water flow are presented in table 6.4 and plotted as shown in figure 6.5

Table 6.4 Static water level

Well No.	Static water level (m)
NL1	-1.55
NL2	-1.791
NL3	-3.383

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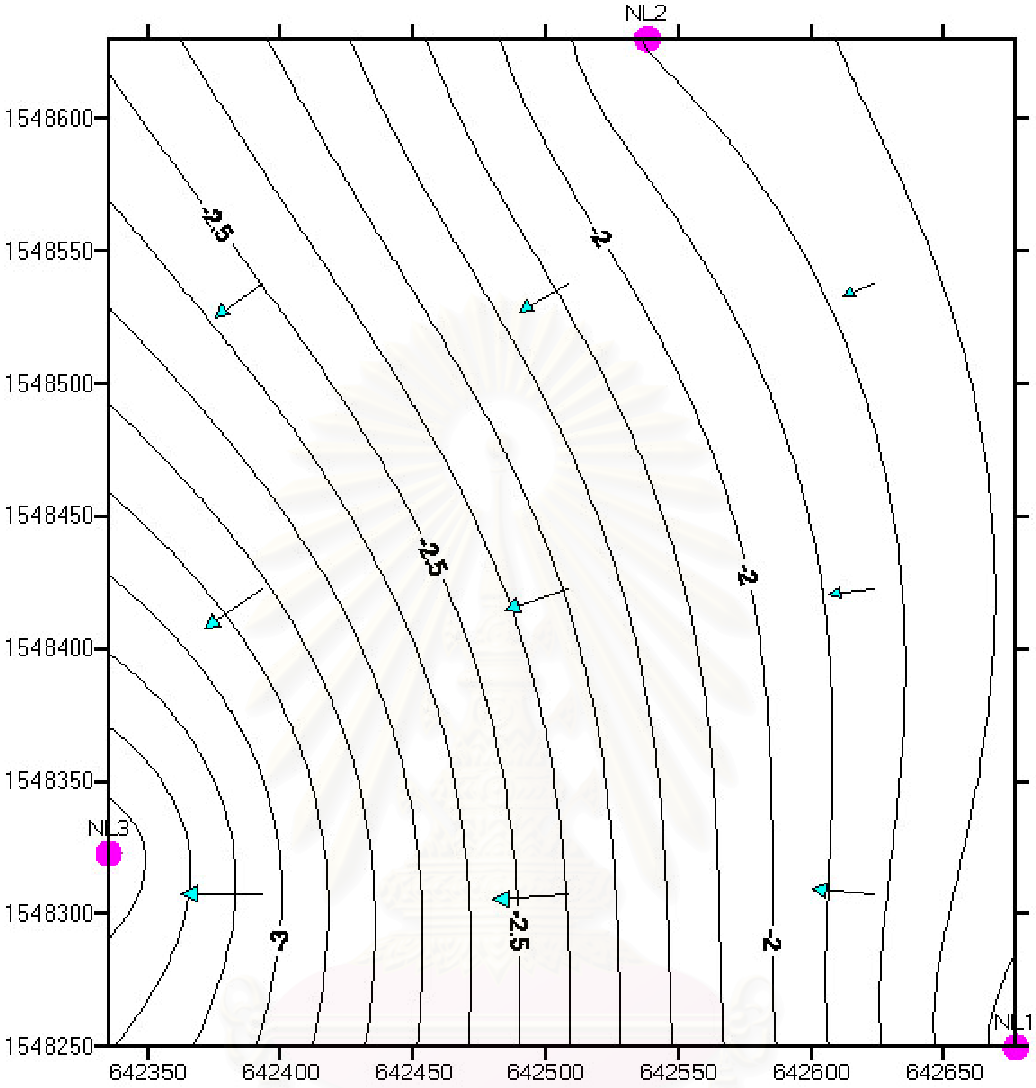

Figure 6.5 Contour line map showing flow direction

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6.3 Water Analysis

The results of water analysis of leachate, shallow subsurface and deep subsurface water and surface water are summarized in Tables 6.5, 6.6 and 6.7 and presented in details in Appendix II. Moreover the concentration contour maps were plotted and shown in Appendix III.

Table 6.5 The results of shallow subsurface water and leachate analysis.

Parameter	Unit	NL1	NL2	NL3	NL4	Leachate	Groundwater Quality Standards
pH		4.5 – 6.2	6.2	5.8 – 6.2	7.5 –7.6	8.7	-
Conductivity	µS/cm	6,800-8,260	5,830-7,950	4,210-5,540	3,100 –4,500	29,700	-
DO	mg/l	1.6 –5.6	1.6 –2.0	1.0 - 4.3	2 – 2.2		-
TDS	mg/l	3,690 - 4,543	2,526– 4,372.5	2,739– 3,498	1,705-2,592	16,355	-
Total hardness	mg/l	1,340.0-3,325.39	1,820.0 – 2,840.52	1,064.0 – 1,672.52	1,137.1 – 1,394.22	5,541.10	-
Mercury	µg/l	<1-2.67	<1- 3.53	<1- 27.66	0.16 - 0.18	4.56	1
Chromium	mg/l	0.09-0.25	0.1-0.18	0.08-0.16	0.19-0.21	0.89	-
Cadmium	mg/l	0.03-0.2	0.04-0.18	0.02-0.17	0.02-0.04	0.54	0.003
Lead	mg/l	0.13-0.408	0.052-0.39	0.02-0.39	0.17-0.2	0.75	0.01
Zinc	mg/l	0.32-0.95	0.15 - 0.25	0.15 - 0.45	0.03 - 0.05	1.47	5.0
Arsenic	µg/l	<3 -13.79	10.92-37.93	<3-110.4	7.65 - 9.32	175	10
Magnesium	mg/l	269.30-436.79	179.50-217.8	149.2-180.73	97.85-128.64	750.45	-
Calcium	mg/l	447.75-613.82	539.86-779.02	301.80-372.61	294.35-346.72	985.7	-
Sodium	mg/l	669.20-780.91	594.00-632.68	533.80-622.25	158.42-180.48	1125.4	-
Potassium	mg/l	16.50-43.48	7.70-33.69	22.20-50.82	21.64-36.79	80.64	-
Copper	mg/l	0.15-0.71	0.26-0.65	0.06-0.42	0.38 - 0.39	1.57	1
Manganese	mg/l	7.6-10.31	6.57-7.4	2.68-4.66	1.63-1.94	15.84	0.5
Iron	mg/l	4.28-79.00	31.00-65.00	1.86-62.00	0.45-0.64	95.35	-
Sulfide	mg/l	<0.01-0.05	<0.01	<0.01-0.04	0.10 – 0.03	0.7	-

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Table 6.6 The results of deep subsurface water analysis.

Parameter	Unit	ND1	ND2	ND3	ND4	ND5	ND6	ND7	ND8	ND9	Groundwater standard for drink purpose
pH		7.1 – 7.8	7.1 - 7.8	6.6 - 7.8	7.3 -7.8	7.2 – 7.8	7.5 – 7.7	7.6	7.9 – 8.2	7.4 – 7.8	-
Conductivity	µS/cm	512 – 542	495 - 534	504 – 545	666 - 729	514 - 530	555 - 557	541 - 543	532 –543	525 – 537	-
DO	mg/l	1.0 - 3.7	0.9 – 2.4	2.7 – 4.1	4.7 – 5.2	1.8 – 2.1	3.1 – 3.5	2.5 – 3.1	3.3 – 4.2	2.5 – 3.4	6.5-9.2
TDS	mg/l	249.60 - 307.20	237.60 – 259.00	241.92 – 261.60	324.00 – 349.92	246.72 – 257.00	267.36 –269.00	260.64 – 267.00	255.36 – 262.00	254.00 – 257.76	-
Total hardness	mg/l	121.82 – 197.21	120.00 – 270.08	131.24 – 256.82	155.28 – 283.50	160.91 - 539.85	254.79 – 276.47	206.93 - 201.39	223.40 – 234.41	239.47 – 243.79	500
Mercury	µg/l	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1
Chromium	mg/l	0.08 – 0.15	0.08 – 0.19	<0.05 – 0.20	0.08 – 0.27	<0.05 –0.09	0.15 – 0.18	0.13 – 0.17	0.06– 0.08	0.12 – 0.14	-
Cadmium	mg/l	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	0.01
Lead	mg/l	<0.1 – 0.30	<0.1 – 0.30	<0.1 – 0.15	0.15 – 0.33	<0.1 – 0.24	0.13 – 0.26	0.17 – 0.26	0.10 – 0.22	<0.1 – 0.18	0.05
Zinc	mg/l	0.40 – 1.10	<0.02 - 0.04	<0.02 – 0.063	0.34 – 0.65	0.06 – 0.4	0.07 – 0.11	0.13 – 0.14	<0.02 – 0.07	0.22 – 0.32	15
Arsenic	µg/l	<3 – 4.59	<3 – 9.6	<3	5.64 – 7.32	<3 – 4.08	4.44 – 9.43	<3 – 3.08	<3 – 3.52	3.33 – 7.45	0.05
Magnesium	mg/l	7.6 – 10.6	8.2 – 10.0,	7.4 – 10.0	12.5 – 13.5	8.7 – 96.0	6.7 – 7.6	7.3 – 8.4	8.3 – 8.5	7.9 - 9.2	-
Calcium	mg/l	32.00 – 65.00	31.60 – 92.45	37.90 – 88.46	40.30 – 92.90	47.80 – 70.46	89.45 – 99.60	66.78 – 70.80	75.30 – 80.15	80.70 – 84.56	-
Sodium	mg/l	66.06 –95.19	81.30 – 91.63	74.20 – 93.45,	97.80 – 107.70	78.90 – 87.60	82.45 – 83.90	101.45 – 112.30	77.80 – 84.65	72.70 – 75.94	-
Potassium	mg/l	1.20 – 10.30	3.06 – 3.81	2.98 – 3.69	2.98 – 4.81	2.40 – 6.70	3.08 – 3.14	2.57 – 2.94	3.45 – 3.50	3.76 – 3.86	-
Copper	mg/l	<0.05 – 0.14	0.06 – 0.16	<0.05 – 0.17	0.06 – 0.13	0.09 – 0.32	0.06 - 0.09	<0.05– 0.09	<0.05 – 0.11	<0.05 – 0.11	1.5
Manganese	mg/l	0.01– 0.30	0.01-0.40	0.05-0.38	0.03 – 0.10	0.05 – 0.28	0.03 - 0.04	0.04 - 0.05	<0.01	<0.01	0.5
Iron	mg/l	<0.1	<0.1	<0.1 – 0.12	<0.1 – 0.52	<0.1 – 0.26	<0.1	<0.1	<0.1	<0.1	1.0

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Table 6.7 The results of surface water analysis

Parameter	Unite	NS1	NS2	NS3	NS4	NS5	NS6	NS7	Surface water standard
pH		7.8 – 8.0	7.5 – 7.6	7.6 -7.7	7.0 – 7.1	7.2 – 7.3	7.1 – 7.5	6.7 – 7.5	5-9
Conductivity	µS/cm	9850 - 11,280	2,360 –2,820	351 - 752,	472 - 658	345 - 712	382 - 645	357 – 525	-
DO	Mg/l	5.6 – 7.0	3.1 – 4.2	3.5 – 4.8	2.7 – 3.6	2.8 – 3.5	3.1 – 3.4	1.1 – 6.8	-
TDS	Mg/l	5,122.0 -5,865.60	1227.2 – 1466.4	168.48 – 360.96	226.56 – 315.84	165.60 – 341.76	183.36 – 309.60	171.36 – 252.00	-
Total hardness	Mg/l	1,853.2 – 2102.14	617.41 – 769.35	215.74 – 287.94	252.91 – 332.79	246.47 –307.14	290.31 – 362.64	221.21 – 330.14	-
Mercury	µg/l	1.132 – 1.459	< 1	< 1	< 1	< 1	< 1	< 1	2
Chromium	Mg/l	0.1 – 0.30	0.18 – 0.36	0.2– 0.34	0.17– 0.20	0.17 – 0.21	0.15 – 0.23	0.07 – 0.18	-
Cadmium	Mg/l	<0.02 – 0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.005
Lead	Mg/l	0.28-0.30	<0.01-0.13	<0.1	0.01-0.04	<0.01	<0.01	0.07-0.14	0.05
Zinc	Mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	1.0
Arsenic	µg/l	<3 - 9.23	3.28-6.99	<3	<3 -7.00	9.34-12.00	<3 -4.31	3.31-8.62	0.01
Magnesium	Mg/l	224.8-237.9	85.1-101.7	11.4-20.9	13.5-20.7	11.7-20.6	15.9 - 25.4	11.4 – 15.6	-
Calcium	Mg/l	368.15-450.70	127.90-150.75	65.60-80.90	76.40-101.30	77.90-97.60	76.10-103.40	62.90-110.90	-
Sodium	Mg/l	280.30-304.57	230.43-295.30	25.90-46.30	38.49-63.20	28.30-34.60	47.99-76.90	25.53-45.10	-
Potassium	Mg/l	59.85-69.82	33.21-37.62	4.63-6.64	4.39-5.97	4.78-5.84	4.65-5.79	5.09-6.34	-
Copper	Mg/l	<0.05 - 0.089	0.06 - 0.09	0.06 - 0.1	0.08 - 0.09	0.06-0.09	<0.05 - 0.09	<0.05 - 0.08	0.1
Manganese	Mg/l	0.53 – 0.67	0.16 – 0.21	0.06 – 0.69	0.08 – 0.10	0.06 – 0.084	0.047 – 0.064	0.29 – 0.5	1.0
Iron	Mg/l	0.27 – 0.45	0.28-0.40	0.54-0.72	0.49-0.74	0.57-0.73	0.74 – 0.98	0.60-2.30	-
Sulfide	Mg/l	0.04 – 0.06	0.01 – 0.03	< 0.01	<0.01	<0.01	0.16 – 0.47	<0.01 – 0.03	-

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6.3.1 Subsurface Water

6.3.1.1 Shallow Well

From the analysis result of each of 23 parameters, the concentration in NL4 is the lowest among all 4 locations, since NL4 situated upstream NE of the disposal site. However the concentration of each parameter of NL4 still exceeds the water quality standard. NL1 and NL2 illustrate the highest concentration, because NL1 located very near the waste mass, only 10 m. away underground (figure 3.6) while NL2 situated near the leachate collection pond. and the soil profile comprises sandy clay layer (figures 3.6 and 3.7). NL3, which located downflow of the disposal site, contains moderate concentration of each parameter and exceeds the water quality standard. This could suggest that there is some degree of contamination.

It may conclude that both the dispersion and advection are the processes involved in the contamination transportation. But the dispersion is the dominant process, which controls the plume. Because of low hydraulic conductivity of soil, which is 5.9 x 10^{-5} cm/sec (Consultant of Technology, 1998), the plume tends to be move somewhat slowly, stay relatively compact (Fetter, 1988) and less elongated (Palmer, 1991). Additionally, the geochemical natural of the water will change due to thermal and chemical interaction during flow (Tohn, 1984). Hence, the concentration decrease through the distance away from the disposal site.

Moreover, the molecular diffusion, a type of dispersion, plays some role by which both ionic and molecular species being dissolved in water move from the area of higher concentration to the area of lower concentration. It become important in contaminant in fine grained deposite as clay and also in heterogeneous deposits, like silty clay. (Cherry and Grlliam, 1984)

Accordingly, the contamination is high near the dump site and lesser through the distance away from the disposal site, such as the up-flow-direction NL4 in this case.

If the advection is the important process, the high concentration must also be found in NL3. Which located down the flow direction from the disposal site.

Finally the seasonal change is seam not to pose any effect on the concentration of the contamination. But this could be due to the unusal climate condition by which during the sampling period in October 2001, there was still heavy rain.

6.3.1.2 Deep Well

There is no significant difference, whatsoever of the concentration of each parameter of all nine localities ND1-ND9, and the water quality meet the groundwater quality standard for drinking water (Appendix IV) except for Pb, which might come from the steel water pipe itself.

6.3.2 Surface water

The result of chemical analysis of surface water samples, NS1-NS7 can be categorized into 2 groups

1) NS1 and NS 2 are the still water body of borrow pit and pond ; 16 m. and 3 m. in depth resepectivity. The concentration of 23 parameters as a whole exceeds the water quality standard for domestic use. It indicates some contamination, as it might come from occasional spillage and/or seepage through the upper layer of the sandy clay.

2) NS3-NS7 are the flowing irrigation canals. The analyzed water quality meets the surface water quality standard, except Pb and classify as surface water class 2-4.It could be explained that this is a flowing irrigation system. The water flows from the water gate, and is drawn in to the paddy field and vegetable farm along the canals. The non-stopped water flowing thus might dilute any contamination concentration, if there is one.

6.4 Modflow plot (figure 6.6)

Generally, the flow direction of water goes down to Khlong Na Mon and Khlong Ha Roi, which surround the disposal site and are the lowest part of the area. At the disposal area, it flows from NL1 and NL2 to NL3, which concur with result from surfer plot (figure 6.5).

Modflow plot is only a prediction, because some parameters used for plotting are the theoretical values and from the nearby area. The field testing of all parameters must be done for a more accurate result

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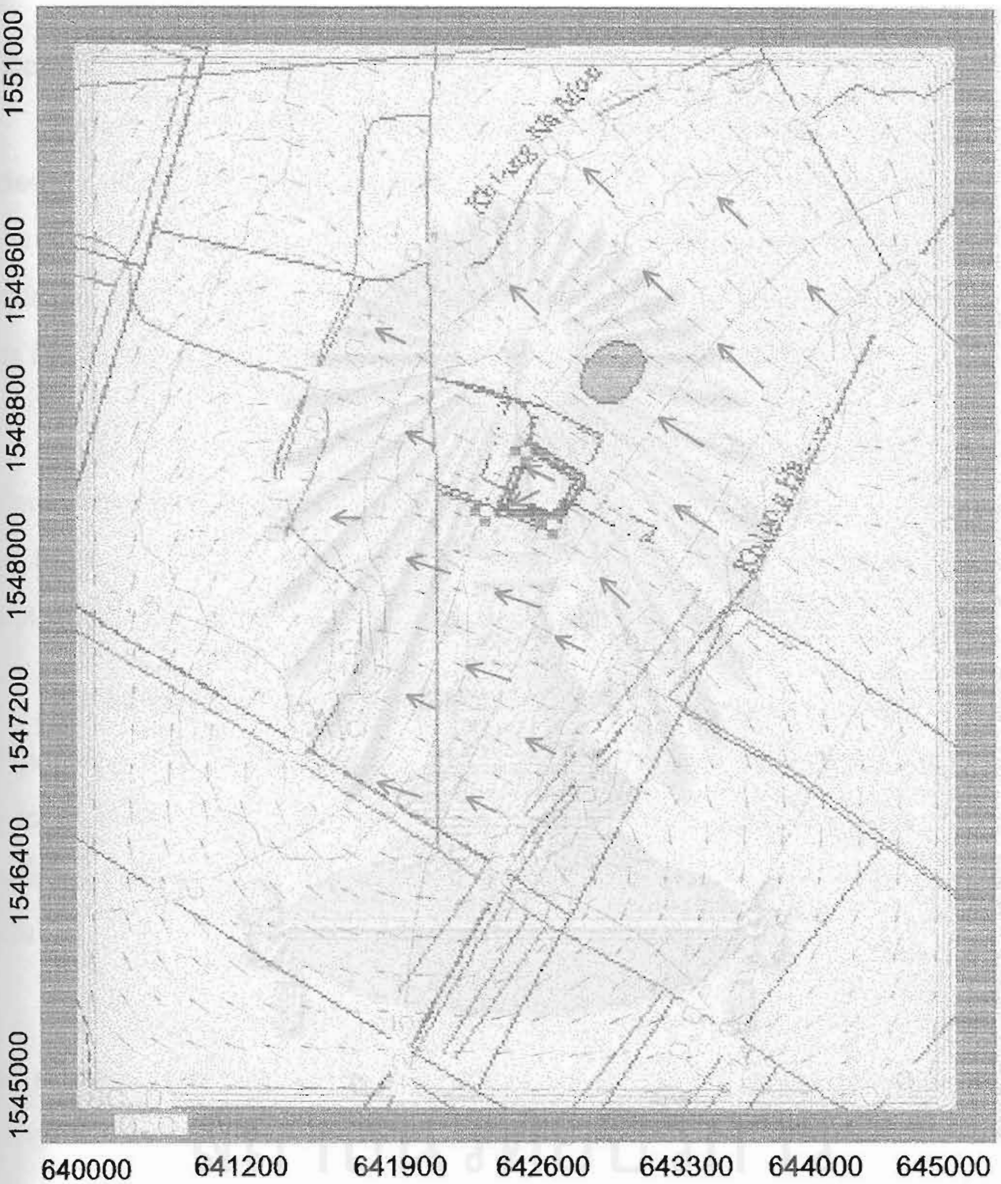

Project: Nonthaburi, disposal site	Visual MODFLOW v.2.8.0, © 1995-1997
Description: flowline	Waterloo Hydrogeologic, Inc.
21 Apr. 03	NC: 25 NR: 30 NL: 40
	Current Layer: 1

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Figure 6.6. Modflow plot of shallow subsurface water flowage. Detailed description is as in § 6.4

CHAPTER VII

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

Surface and subsurface water contamination from Sainoi disposal site was studied by analyzing water samples, covering the disposal area and within the redius of 2 km beyong. These include 4 shallow subsurface wells, 9 deep subsurface wells and 7 surface water sample sites**.** The samplings were done 5 times in the period of 12 months from August 2001 to June 2002.

Results of the water analysis indicate some contamination occurred in the shallow subsurface level, whereas the deeper part are without any disturbance, since the water quality still meet the water quality standard for drinking purpose except Pb content, which suspect to come from the water pipe.

The evidence of some contamination found in the borrow pit, NE of the site and the pond, NW of the disposal site seems to indicate the leakage of leachate did occur either from seepage through top layer of sandy clay or by some occasional spillage. But the affect does not show up in the flowing irrigation canals.

The degree of contamination could be expressed by the result of chemical water analysis. The direction and extent of contamination could be shown by the existing contour line plot of each parameter of water analysis and MODFLOW plot.

The pattern of observed contamination in the shallow subsurface water source, together with the knowledge of the flowage of the water from NE to SW, suggests that the process of contamination from the disposal site is mainly dispersion.

7.2 Recommendation

Further work should be carried on the minimize to environmental impact in the long time period as recommends:

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1) In order to define the plume of the contamination in both horizontal and vertical directions, the number of monitoring wells should be increased at different depth, and further downflow and upflow. Moreover the reliable groundwater monitoring approaches are suggested. These existing three monitoring wells, which was drilled by Pollution Control Department, are under the care of the Provincial Adiminitration Office of Changwat Nonthaburi at present.

2) Other environmental impact should be investigated such as soil, sediment, crops and aquatic lifes to ensure that any changes in environmental conditions at the site and its vicinity are identified and addressed in the update assessments.

3) This disposal site should be closed and sealed off since it has been used up to its full capacity and now the disposal is overload. Furthermore the disposal site locates within the area, which is oftenly flooded though the period stagnation is short. (Ohkura, et al., 1989)

4) Post-closure of the site needs further monitoring process to ensure the safety and keep an eye on the sandy clay layer, which rather high permeability. If possible, seal off this layer to protect the leachate leakage. The time duration for this post-closure monitoring should be well further in the future until it is proved that there is no more threat from this disposal site.

5) Another alternative waste disposal site should be considered, and be well planned and studied.

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APPENDICES

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APPENDIX I

HYDROCHEMISTRY

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pH

The acidity or basic nature of a solution is expressed as the pH. The concentration of the hydrogen ion $[H^+]$ in a solution determines the pH. Mathematically this is expressed as:

$$pH = -\log [H^+]$$

The pH value is the exponent to the base 10 of the hydrogen ion concentration. The more acidic the solution, the lower the pH; the more basic, the higher the pH. Each change in pH unit represents a tenfold change in acidity. In natural waters this usually is dependent on the carbonic acid equilibrium. When carbon dioxide from the air enters freshwater, small amounts of carbonic acid are formed which then dissociate into hydrogen ions and bicarbonate ions, as shown in the following equations.

$$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ (carbonic acid)}$$

$$H_2CO_3 \longrightarrow HCO_3^- + H^+$$

This increase in H^+ ions makes the water more acidic and lowers the pH. If CO_2 is removed (as in photosynthesis) the reverse takes place and pH rises. This process is also related to the presence of carbonates, of calcium or other ions such as magnesium as discussed under alkalinity.

(Note: H^+ ions actually occur as hydronium ions H_3O^+ [hydrated protons]; however, for simplicity, they have been represented as H^+.)

Environmental Impact: A pH range of 6.0 to 9.0 appears to provide protection for the life of freshwater fish and bottom dwelling invertebrates.

One of the most significant environmental impacts of pH is the affect that it has on the solubility and thus the bioavailability of other substances. This process is important in surface waters. Runoff from agricultural, domestic, and industrial areas may contain iron, lead, chromium, ammonia, mercury or other elements. The pH of the water affects the toxicity of these substances. As the pH falls (solution becomes more acidic) many insoluble substances become more soluble and thus available for absorption. For example, 4 mg/L of iron would not present a toxic

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effect at a pH of 4.8. However, as little as 0.9 mg/L of iron at a pH of 5.5 can cause fish to die.

Table I.1 Some special effects of pH on fish and aquatic life.

Limiting pH Values		
Minimum	Maximum	Effects
3.8	10.0	Fish eggs could be hatched, but deformed young were often produced
4.0	10.1	Limits for the most resistant fish species
---	8.7	Upper limit for good fishing waters
5.4	11.4	Fish avoided waters beyond these limits
6.0	7.2	Optimum (best) range for fish eggs
1.0	---	Mosquito larvae were destroyed at this pH value
3.3	4.7	Mosquito larvae lived within this range
7.5	8.4	Best range for the growth of algae

Conductivity

Conductivity is a measurement of the ability of an aqueous solution to carry an electrical current. An ion is an atom of an element that has gained or lost an electron, which will create a negative or positive state. For example, sodium chloride (table salt) consists of sodium ions (Na^+) and chloride ions (Cl^-) held together in a crystal. In water it breaks apart into an aqueous solution of sodium and chloride ions. This solution will conduct an electrical current. An equation that shows this is:

$$\text{Na (atom)} + \text{Cl (atom)} \longrightarrow Na^+ Cl^- \text{ (ionic crystal)}$$

$$Na^+Cl^- \text{ (in a water solution)} \longrightarrow Na^+ \text{ (ion)} + Cl^- \text{ (ion)}$$

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There are several factors that determine the degree to which water will carry an electrical current (John, 1975). These include:

1) The concentration or number of ions;
2) Mobility of the ion;
3) Oxidation state (valence) and;
4) Temperature of the water.

Resistance, which is an electrical measurement expressed in ohms, is the opposite of conductivity. Conductivity is then expressed in reciprocal ohms. A more convenient unit of measurement in the chemical analysis of water is micromhos. The specific conductance or conductivity measurement is related to ionic strength and does not tell us what specific ions are present.

Environmental Impact: Conductivity is a measurement used to determine a number of applications related to water quality. These are as follows:

1) Determining mineralization: this is commonly called total dissolved solids. Total dissolved solids information is used to determine the overall ionic effect in a water source. Certain physiological effects on plants and animals are often affected by the number of available ions in the water.
2) Noting variation or changes in natural water and wastewater quickly;
3) Estimating the sample size necessary for other chemical analyses; and
4) Determining amounts of chemical reagents or treatment chemicals to be added to a water sample.

Elevated dissolved solids can cause "mineral tastes" in drinking water. Corrosion or encrustation of metallic surfaces by waters high in dissolved solids causes problems with industrial equipment and boilers as well as domestic plumbing, hot water heaters, toilet flushing mechanisms, faucets, and washing machines and dishwashers. Indirect effects of excess dissolved solids are primarily the elimination of desirable food plants and habitat-forming plant species. Agricultural uses of water for livestock watering are limited by excessive dissolved solids and high dissolved solids can be a problem in water used for irrigation.

Criteria: Water quality criteria have been established only for the mainstem of the Ohio River. The limit is 800 micromhos/cm or 500 mg/L total dissolved solids.

Total Dissolved Solids

Total dissolved solids (TDS), is defined as the concentration of all dissolved minerals in the water. TDS are a direct measurement of the interaction between groundwater and surface minerals. High TDS, greater than 1,000 mg/l, is commonly offensive to taste. TDS level over 2,000 mg/l are generally considered undrinkable due to strongly offensive taste. A higher concentration of TDS usually serves as no heath threat to humans unit the values exceed 10,000 mg/l. At this level the water is considered saline water and defined as undrinkable. A high TDS (levels above 1,000 mg/l) may cause corrosion of pipes and plumbing systems. Table I.2 presents a groundwater classification system based on total dissolved solids (Freeze and Cherry, 1979).

Table I.2 Simple groundwater classification based on Total Dissolved Solids

Category	Total Dissolved Solids (mg/l)
Fresh water	0-1,000
Brackish water	1,000-10,000
Saline water	10,000-100,000
Brine water	More than 100,000

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Hardness

Hardness is due to the presence of multivalent metal ions, which come from minerals dissolved in the water. Hardness is based on the ability of these ions to react with soap to form a precipitate or soap scum.

In fresh water the primary ions are calcium and magnesium; however iron and manganese may also contribute. Carbonate hardness is equal to alkalinity but a non-carbonate fraction may include nitrates and chlorides.

Table I.3 Classification of Water by Hardness Content

Concentration mg/L $CaCO_3$	Description
0 – 75	soft
75 – 150	moderately hard
150 – 300	hard
300 and up	very hard

Environmental Impact: The most important impact of hardness on fish and other aquatic life appears to be the affect the presence of these ions has on the other more toxic metals such as lead, cadmium, chromium and zinc. Generally, the harder the water, the lower the toxicity of other metals to aquatic life. In hard water some of the metal ions form insoluble precipitates and drops out of solution and is not available to be taken in by the organism. Large amounts of hardness are undesirable mostly for economic or aesthetic reasons. If a stream or river is a drinking water source, hardness can present problems in the water treatment process. Hardness must also be removed before certain industries can use the water. For this reason, the hardness test is one of the most frequent analyses done by facilities that use water.

Criteria: There are no criteria for hardness.

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Calcium

Calcium salts and calcium ions are among the most commonly occurring in nature. They may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes. Calcium is usually one of the most important contributors to hardness. Even though the human body requires approximately 0.7 to 2.0 grams of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones. High concentrations of calcium can also be detrimental to some industrial processes. Thus, both domestic and industrial water users have to consider calcium concentrations. Calcium also serves an important role in the health of bodies of water. In natural water it is known to reduce the toxicity of many chemical compounds on fish and other aquatic life.

Magnesium

Magnesium is widely distributed in ores and minerals. It is also very chemically active; therefore it is not found in the elemental state in nature. With the exception of magnesium hydroxide, which has a high pH value, its salts are very soluble. Magnesium ions are of particular importance in water pollution. They may contribute to water hardness. Concentrations of magnesium and calcium in water may also be a factor in the distribution of certain crustaceans, fish and other organisms in streams.

Sodium

Sodium is a very active metal, and therefore does not occur freely in nature. The aquatic toxicity encountered with sodium depends largely on the anion involved; chromate is extremely toxic and sulfate is the least toxic. High sodium levels in drinking water can have adverse effects on humans with high blood pressure or pregnant women suffering from toxemia.

Criteria: No criteria exist for this metal.

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Iron

Iron is the fourth most abundant element, by weight, in the earth's crust. Natural waters contain variable amounts of iron depending on the geological area and other chemical components of the waterway. Iron in groundwater is normally present in the ferrous or bivalent form [Fe^{2+}] that is soluble. It is easily oxidized to ferric iron [Fe^{3+}] or insoluble iron upon exposure to air. This precipitate is orange-colored and often turns streams orange.

Environmental Impact: Iron is a trace element required by both plants and animals. It is a vital part of the oxygen transport mechanism in the blood (hemoglobin) of all vertebrate and some invertebrate animals. Ferrous Fe^{2+} and ferric Fe^{3+} ions are the primary forms of concern in the aquatic environment. Other forms may be in either organic or inorganic wastewater streams. The ferrous form Fe^{2+} can persist in water void of dissolved oxygen and usually originates from groundwater or mines that are pumped or drained. Iron in domestic water supply systems stains laundry and porcelain. It appears to be more of a nuisance than a potential health hazard. Taste thresholds of iron in water are 0.1 mg/L for ferrous iron and 0.2 mg/L ferric iron, giving a bitter or an astringent taste. Water to be used in industrial processes should contain less than 0.2 mg/L iron. Black or brown swamp waters may contain iron concentrations of several mg/L in the presence or absence of dissolved oxygen, but this iron form has little effect on aquatic life.

Criteria: The current aquatic life standard is less than 1.0 mg/L based on toxic effects. (It is one of the few for which the criterion is not calculated based on hardness.)

Manganese

Manganese is a transition element, which is gray, white or silver in color. It is soft and ductile if pure but usually occurs in compounds. In natural waters it rarely exceeds 1 mg/L. At 0.1 mg/L, taste and staining problems may occur. Manganese forms a number of salt compounds. These compounds can include $KMnO_4$ (potassium permanganate) and K_2MnO_3 (potassium manganate). Frequently manganese salts will occur in association with iron salts. The primary uses of manganese are in metal alloys, dry cell batteries, and micro-nutrient fertilizer additives.

Environmental Impact: Manganese is a vital micro-nutrient for both plants and animals. When not present in sufficient quantities, plants exhibit a yellowing of leaves (chlorosis) or failure of the leaves to develop properly. Inadequate quantities of manganese in domestic animal food result in reduced reproduction ɪ deformed or poorly maturing young. In humans, very large doses of ingested nganese can cause some diseases and liver damage, but these are not known occur in the United States. Permanganates have been reported to kill fish in 8 18 hours at concentrations of 2.2 to 4.1 mg/L, but they are not persistent. anganese is not known to be a problem in water consumed by livestock. No ecific criterion for manganese has been proposed for agricultural waters. nsumer complaints arise when high levels of manganese are found in drinking ater or domestic water because of the brownish staining of laundry and jectionable tastes in beverages, which may occur.

iteria: Water to be used, as a domestic water source should contain less than 0.05 g/L manganese.

itrogen

Nitrogen is one of the most abundant elements. About 80 percent of the air e breath is nitrogen. It is found in the cells of all living things and is a major omponent of proteins. Inorganic nitrogen may exist in the free state as a gas N_2, r as nitrate NO_3^-, nitrite NO_2^- or ammonia NH_3. Organic nitrogen is found in roteins, and is continually recycled by plants and animals. The nitrogen cycle is shown below:

Environmental Impact: Nitrogen-containing compounds act as nutrients in streams, rivers, and reservoirs. The major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes (including birds and fish), runoff from fertilized agricultural field and lawns and discharges from car exhausts. Bacteria in water quickly convert nitrites $[NO_2^-]$ to nitrates $[NO_3^-]$ and this process uses up oxygen. Excessive concentrations of nitrites can produce a serious condition in fish called "brown blood disease." Nitrites also can react directly with hemoglobin in the blood of humans and other warm-blooded animals to produce methemoglobin. Methemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious in babies under three months of age. It causes a condition known as methemoglobinemia or "blue baby" disease. Water with nitrate

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levels exceeding 1.0 mg/L should not be used for feeding babies. High nitrates in drinking water can cause digestive disturbances in people. Nitrite/nitrogen levels below 90 mg/L and nitrate levels below 0.5 mg/L seem to have no affect on warm water fish.

The major impact of nitrates/nitrites on fresh water bodies is that of enrichment or fertilization called eutrophication. Nitrates stimulate the growth of algae and other plankton which provide food for higher organisms (invertebrates and fish); however an excess of nitrogen can cause over-production of plankton and as they die and decompose they use up the oxygen which causes other oxygen-dependent organism to die.

Criteria: Nitrates/nitirites should remain below 10 mg/L in water to be used as a domestic water supply.

Ammonia

Ammonia (NH_3) is a colorless gas with a strong pungent odor. It is easily liquefied and solidified and is very soluble in water. One volume of water will dissolve 1,300 volumes of NH_3. Ammonia will react with water to form a weak base.

Environmental Impact: The fertilizers, either as the compound itself or as ammonium salts such as sulfate and nitrate is utilised. Large quantities of ammonia are used in the production of nitric acid, urea and nitrogen compounds. It is used in the production of ice and in refrigerating plants. "Household ammonia" is an aqueous solution of ammonia. It is used to remove carbonate from hard water. Since ammonia is a decomposition product from urea and protein, it is found in domestic wastewater. Aquatic life and fish also contribute to ammonia levels in a stream.

NH_3 is the principal form of toxic ammonia. It has been reported toxic to fresh water organisms at concentrations ranging from 0.53 to 22.8 mg/L. Toxic levels are both pH and temperature dependent. Toxicity increases as pH decreases and as temperature decreases. Plants are more tolerant of ammonia than animals, and invertebrates are more tolerant than fish. Hatching and growth rates of fishes may be affected. In the structural development, changes in tissues of gills, liver, and kidneys may also occur. Toxic concentrations of ammonia in humans may cause loss of equilibrium, convulsions, coma, and death.

Criteria: The un-ionized form of ammonia (NH_3) should not exceed 0.05 mg/L in order to protect aquatic organisms. This is calculated from total ammonia using temperature and pH in a formula.

Sulfur

Sulfur appears in two species, that of sulfide (S^{2-}) and sulfate (SO_4^{2-}). Sulfide is generally in the form of dissolved hydrogen sulfide gas (H_2S). Sulfides originate from areas such as marshes, oil wells, mines, and manure pits. Sulfates are principally drived from the dissolving of minerals such as gypsum ($(CaSO_4).2H_2O$) and anhydrite ($CaSO_4$). Secondary sources of sulfates are from the weathering of pyrite and the dissolving of ammonium sulfate fertilizer. Hydrogen sulfide gives the characteristic rotten egg smell that is familiar to many people. Sulfides can cause corrosion to plumbing, darken water, and create a foul odor and taste. Sulfates, at high level, taint the taste of water and may crate a laxative effect.

Metals

The metals include calcium, magnesium, and iron, which play major roles in water chemistry. Other metals include sodium, nickel, cadmium, chromium, lead, manganese, mercury, arsenic and zinc, which tend to be present in smaller amounts. The toxicity of metals is dependent on their solubility and this in turn, depends heavily on pH and on the presence of different types of anions and other cations.

Environmental Impact: Metal ions are dissolved in groundwater and surface water when the water comes in contact with rock or soil containing the metals, usually in the form of metal salts. Metals can also enter with discharges from sewage treatment plants, industrial plants, and other sources. The metals most often found in the highest concentrations in natural waters are calcium and magnesium. These are usually associated with the carbonate anion (CO_3^{2-}) and come from the dissolution of limestone rock. If the water is hard, the toxicity of a given concentration of a toxic metal is reduced. Conversely, in soft, acidic water the same concentrations of metals may be more toxic.

High pH in a stream can cause precipitation of metal salts which makes them temporarily unavailable. Because of this relationship of toxicity to hardness, Warm Water Aquatic Habitat Criteria for metals are calculated by a rather complex mathematical formula employing the natural log of the hardness. As hardness increases, the allowable concentration increases. The metal criteria in this manual were calculated based on a hardness of 100 mg/L. If the hardness values in the test results vary much from 100 mg/L, the criteria can be recalculated. Even though metal concentrations may be very low (below a toxic level), aquatic organisms can bioaccumulate (or concentrate) certain metals (for example, mercury, lead, and cadmium). If more is absorbed than excreted, the levels can then build up over time to a toxic level.

When looking at the metals individually, the intended use of the water is very important. Industry requires varying amounts of metals and or hardness for many of its manufacturing techniques, while agriculture has its own requirements.

Cadmium

Cadmium is a non-essential element and it diminishes plant growth. It is considered a potential carcinogen. It also has been shown to cause toxic effects to the kidneys, bone defects, high blood pressure, and reproductive effects. Cadmium is widely distributed in the environment at low concentrations. It can be found in fairly high concentrations in sewage sludge. Primary industrial uses for cadmium are plating, battery manufacture, pigments, and plastics.

Criteria: The standard for domestic water supply is <0.01 mg/L. The allowable level for aquatic life is derived using a formula involving hardness. At a hardness of 100, 0.001 mg/L is considered protective.

Chromium

Chromium is ubiquitous in the environment, occurring naturally in the air, water, rocks and soil. It is used in stainless steel, electroplating of chrome, dyes, leather tanning and wood preservatives. It occurs in several forms, or oxidation states. The two most common are chromium VI and chromium III. The form depends on pH. Natural sources of water contain very low concentrations of chromium. It is a micronutrient (or essential trace element). High doses of chromium VI have been associated with birth defects and cancer; however, chromium III is not associated with these effects. Plants and animals do not bioaccumulate chromium; therefore, the potential impact of high chromium levels in the environment is acute toxicity to plants and animals. In animals and humans this toxicity may be expressed as skin lesions or rashes and kidney and liver damage.

Criteria: The criteria for total chromium in a domestic water supply is 0.05 mg/L. The aquatic life criteria is less than 0.011 mg/L for chromium VI and less than 0.207 mg/L for chromium III. (The second value is based on a formula involving hardness).

Lead

The primary natural source of lead is in the mineral galena (lead sulfide). It also occurs as carbonate, as sulfate and in several other forms. The solubility of these minerals and also of lead oxides and other inorganic salts is low. Major modern day uses of lead are for batteries, pigments, and other metal products. In the past lead was used as an additive in gasoline and became dispersed throughout the environment in the air, soils, and waters as a result of automobile exhaust emissions. For years this was the primary source of lead in the environment. However, since the replacement of leaded gasoline with unleaded gasoline in the mid-1980's, lead from that source has virtually disappeared. Mining, smelting and other industrial emissions and combustion sources and solid waste incinerators are now the primary sources of lead. Another source of lead is paint chips and dust from buildings built before 1978 and from bridges and other metal structures.

Lead is not an essential element. In humans it can affect the kidneys, the blood and most importantly the nervous system and brain. Even low levels in the blood have been associated with high blood pressure and reproductive effects. It is stored in the bones.

Lead reaches water bodies either through urban runoff or discharges such as sewage treatment plants and industrial plants. It also my be transferred from the air to surface water through precipitation (rain or snow). Toxic to both plant and animal life, lead's toxicity depends on its solubility and this, in turn, depends on pH and is affected by hardness.

Criteria: The level considered protective for aquatic life at a hardness of 100 is less than 0.003 mg/L. Use as a domestic water source requires less than 0.05 mg/L. Drinking water must contain less than 0.015 mg/L.

Zinc

Zinc is found naturally in many rock-forming minerals. Because of its use in the vulcanization of rubber, it is generally found at higher levels near highways. It also may be present in industrial discharges. It is used to galvanize steel, and is found in batteries, plastics, wood preservatives, antiseptics and in rat and mouse poison (zinc phosphide).

Zinc is an essential element in the diet. It is not considered very toxic to humans or other organisms.

Criteria: Criteria for aquatic life has been set at less than 0.106 mg/L based on hardness of 100 mg/L.

Aresenic

Some of the earliest uses of aresenical compounds were as pesticides and herbicides. Lead arsenate was commonly used to control insect. The application of arsenic as a preservative for wood in the compounds cooper-chromium –arsenate and ammonium-cooper-arsenate remain an important use of this semi- metal. Arsenic may also enter the environment through anthorogenic input as an aerosol created by the smelting of copper, lead, zinc and gold ores and by coal combustion. The particulate in the atmosphere may contaminate downwind soils. Also, arsenic may leach from the ash produced by burning coal.

The dominant redox states of arsenic in the environment are As (III) and As(V). Under slightly oxidizing conditions and above (pe + pH>8), As(V) is the stable redox species while under more reducing conditions As(III) species dominate (Deutsch,1997). Microorganisms can methylate/demethylate arsenic over a wide range of pH and Eh conditions, producing monoethylarsonic acid ($CH_3AsO[OH]_2$); dimethylarsinic acid (cacodylic acid)($[CH_3]_2AsO[OH]$); trimethyl arsenic oxide $(CH_3)_3$ AsO; trimethylarsine $(CH_3)_3As$, and dimethylarsine $(CH_3)_2AsH$. The reactions producing there compounds depend on the type of organism present and the from of arsenic.

In the pH range of natural water, the As(V) species are predominantly anionic($H_2AsO_4^-$) and $HAsO_4^{2-}$). Ferrihydrite has very strong affinity for these species, as well as high capacity for adsorption. It will scavenge arsenic from solution. The As (III) species in water are primarily the neutral species $H_3AsO_3^0$ and the anion $H_2AsO_3^-$. The affinity of ferric hydroxide for dissolved As(III) is less than that for As(V). Under oxidizing conditions, the dissolved concentration of arsenic may be limited by the relatively soluble mineral scorodite ($FeAsO_4.2H_2O$), while under reducing conditions in the presence of sulfide, the insoluble mineral orpiment(As_2S_3) and realgar (AsS) may limit arsenic solution concentrations.

The acute toxicity of As(III) is substantially grater than that of As(V), therefore the transformation between redox species is important from the standpoint of potential risk. Methylated arsenic species are apparently less acutely toxic than inorganic species, and the formation of argano-As compounds by organism may be a mechanism for detoxification of arsenic.

Mercury

Mercury has been well known as an environmental pollutant for several decades.

Drinking water standard and health risk: The primary drinking water standard for mercury is 0.002 milligrams per liter. Mercury can cause acute poisoning in a large dose. Since mercury accumulates in body tissues, it can cause chronic effects to the nervous system, kidney or intestines at low doses over a long period of time. Mercury compounds become concentrated in the tissues of fish; therefore, fish taken from mercury polluted water should not be eaten.

Possible source of contamination: Mercury contamination of water is caused by industrial or agricultural wastes. Like many environmental contaminants, mercury undergoes bioaccumulation. Bioaccumulation is the process by which organisms (including humans) can take up contaminants more rapidly than their bodies can eliminate them, thus the amount of mercury in their body accumulates over time. If for a period of time an organism does not ingest mercury, its body burden of mercury will decline. If, however, an organism continually ingests mercury, its body burden can reach toxic levels. The rate of increase or decline in body burden is specific to each organism. For humans, about half the body burden of mercury can be eliminated in 70 days if no mercury is ingested during that time. Biomagnification is the incremental increase in concentration of a contaminant at each level of a food chain

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APPENDIX II

CHEMICAL ANALYSIS OF SURFACE WATER AND SUBSURFACE WATER

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Table II.1 Data of shallow subsurface water analysis

Parameter	Unit	Date	NL1	NL2	NL3	NL4	Leachate
Depth	m.		13	13	13	< 13	
pH		18 Aug. 01	6.2	6.2	6.2	7.5	
		28 Oct. 01	6.2	6.2	6.0	7.5	
		27 Jan. 02	5.0	6.2	5.8	7.6	
		27 Mar. 02	4.5	well damaged	5.8	7.6	
		27 Jul. 02	5.0	well damaged	6.0	7.6	8.7
Electrical Conductivity	μS /cm	18 Aug. 01	6800	5830	4210	3200	
		28 Oct. 01	7200	6780	5150	3100	
		27 Jan. 02	8260	7950	4980	4500	
		27 Mar. 02	8190	well damaged	5210	3330	
		27 Jul. 02	6950	well damaged	5540	4320	29700
Temperature	°C	18 Aug. 01	32.0	31.0	29.5	30.0	
		28 Oct. 01	31.0	30.0	30.0	30.0	
		27 Jan. 02	32.0	31.0	30.0	30.5	
		27 Mar. 02	31.0	well damaged	30.0	31.0	
		27 Jul. 02	30.9	well damaged	29.4	31.0	33.5
DO	mg/l	18 Aug. 01	2.0	1.6	1.8	2.1	
		28 Oct. 01	1.7	1.8	1.5	2.2	
		27 Jan. 02	1.6	2.0	1.0	2.0	
		27 Mar. 02	1.8	well damaged	1.5	2.1	
		27 Jul. 02	5.6	well damaged	4.3	2.2	
Total Dissolved Solid	mg/l	18 Aug. 01	4080	2526	3498	1920	
(TDS)		28 Oct. 01	3960	3729	2832.5	1705	
		27 Jan. 02	4543	4372.5	2739	2475	
		27 Mar. 02	4504.5	well damaged	2,865.5	1831.5	
		27 Jul. 02	3690	well damaged	2,920	2592	16355
Total Hardness	mg/l	18 Aug. 01	1340	1820	1064	1137.1	
		28 Oct. 01	2707.7	2150.38	1485.86	1198.9	
		27 Jan. 02	3057.54	2840.52	1426.1	1244.78	
		27 Mar. 02	3162.39	well damaged	1585.68	1300.67	
		27 Jul. 02	3325.39	well damaged	1672.52	1394.22	5541.1
Sulfide	mg/l	18 Aug. 01	0.05	0.00	0.01	0.01	
		28 Oct. 01	0.02	0.00	0.02	0.03	
		27 Jan. 02	0.04	0.00	0.04	0.02	
		27 Mar. 02	0.02	well damaged	<0.01	0.01	
		27 Jul. 02	0.01	well damaged	0.03	0.02	0.7
Ammonia Nitrogen	mg/l	18 Aug. 01	95.63	15.89	12.81	4.63	
		28 Oct. 01	66.94	10.62	8.09	3.12	
		27 Jan. 02	108.59	12.14	11.54	4.08	
		27 Mar. 02	79.52	well damaged	10.63	3.52	
		27 Jul. 02	81.12	well damaged	3.30	4.01	890

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จุฬาลงกรณ์มหาวิทยาลัย

Table II.1 Data of shallow subsurface water analysis (cont.)

Parameter	Unit	Date	NL1	NL2	NL3	NL4	Leachate
Nitrate Nitrogen	mg/l	18 Aug. 01	3.12	1.85	1.8	1.65	
		28 Oct. 01	1.94	1.34	1.6	1.78	
		27 Jan. 02	2.73	1.49	1.7	1.82	
		27 Mar. 02	2.50	well damaged	1.5	1.8	
		27 Jul. 02	2.68	well damaged	1.1	1.7	12.84
Mercury (Hg)	μg/L	18 Aug. 01	1.13	3.53	1.18	<1.00	
		28 Oct. 01	< 1.00	1.24	6.41	<1.00	
		27 Jan. 02	<1.00	< 1.00	27.66	<1.00	
		27 Mar. 02	2.67	well damaged	3.40	<1.00	
		27 Jul. 02	1.73	well damaged	0.31	<1.00	4.56
Total Chromium (Cr)	mg/l	18 Aug. 01	0.09	0.10	0.08	0.19	
		28 Oct. 01	0.13	0.15	0.09	0.19	
		27 Jan. 02	0.13	0.18	0.14	0.20	
		27 Mar. 02	0.23	well damaged	0.16	0.21	
		27 Jul. 02	0.25	well damaged	0.14	0.21	0.89
Cadmium (Cd)	mg/l	18 Aug. 01	0.20	0.18	0.17	0.04	
		28 Oct. 01	0.03	0.04	0.03	0.02	
		27 Jan. 02	0.09	0.05	0.06	0.03	
		27 Mar. 02	0.04	well damaged	0.02	0.02	
		27 Jul. 02	0.03	well damaged	0.02	0.02	0.543
Lead (Pb)	mg/l	18 Aug. 01	0.15	< 0.1	< 0.1	0.18	
		28 Oct. 01	0.13	0.17	< 0.1	0.17	
		27 Jan. 02	0.35	0.39	0.29	0.20	
		27 Mar. 02	0.36	well damaged	0.22	0.18	
		27 Jul. 02	0.41	well damaged	0.39	0.19	0.75
Manganese (Mn)	mg/l	18 Aug. 01	8.96	7.26	4.19	1.83	
		28 Oct. 01	7.88	6.57	4.52	1.63	
		27 Jan. 02	10.31	7.40	4.66	1.94	
		27 Mar. 02	9.27	well damaged	4.44	1.81	
		27 Jul. 02	7.60	well damaged	2.68	1.80	15.84
Total Iron (Fe)	mg/l	18 Aug. 01	4.28	31.72	12.78	0.45	
		28 Oct. 01	6.00	31.00	1.86	0.62	
		27 Jan. 02	55.00	65.00	62.00	0.54	
		27 Mar. 02	79.00	well damaged	39.00	0.64	
		27 Jul. 02	61.20	well damaged	35.40	0.68	95.35
Nickel (Ni)	mg/l	18 Aug. 01	0.18	0.21	0.10	0.10	
		28 Oct. 01	0.27	0.30	0.13	0.09	
		27 Jan. 02	0.40	0.44	0.33	0.11	
		27 Mar. 02	0.37	well damaged	0.24	0.12	
		27 Jul. 02	0.31	well damaged	0.07	0.08	0.86

Table II.1 Data of shallow subsurface water analysis (cont.)

Parameter	Unit	Date	NL1	NL2	NL3	NL4	Leachate
Zinc (Zn)	mg/l	18 Aug. 01	0.33	0.15	0.15	0.04	
		28 Oct. 01	0.32	0.22	0.22	0.03	
		27 Jan. 02	0.55	0.25	0.45	0.05	
		27 Mar. 02	0.70	well damaged	0.17	0.03	
		27 Jul. 02	0.95	well damaged	0.22	0.03	1.47
Arsenic (As)	µg/l	18 Aug. 01	6.18	31.29	100.05	8.35	
		28 Oct. 01	<3.0	10.92	<3.0	7.54	
		27 Jan. 02	9.31	37.93	110.40	9.32	
		27 Mar. 02	13.79	well damaged	11.37	8.85	
		27 Jul. 02	7.05	well damaged	12.83	7.65	175
Magnesium (Mg)	mg/l	18 Aug. 01	269.30	176.50	149.20	97.85	
		28 Oct. 01	366.75	195.30	159.68	106.47	
		27 Jan. 02	400.10	217.80	161.27	113.49	
		27 Mar. 02	400.13	well damaged	161.75	119.95	
		27 Jul. 02	436.79	well damaged	180.73	128.64	750.45
Calcium (Ca)	mg/l	18 Aug. 01	447.75	571.90	301.80	294.35	
		28 Oct. 01	481.61	539.86	332.48	304.95	
		27 Jan. 02	566.85	779.02	305.96	311.79	
		27 Mar. 02	608.75	well damaged	369.00	323.55	
		27 Jul. 02	613.82	well damaged	372.61	346.72	985.7
Sodium (Na)	mg/l	18 Aug. 01	669.20	594.00	533.80	158.42	
		28 Oct. 01	677.74	582.16	622.25	164.97	
		27 Jan. 02	655.48	632.68	600.87	170.64	
		27 Mar. 02	721.31	well damaged	572.25	167.85	
		27 Jul. 02	780.91	well damaged	615.74	180.48	1125.4
Potassium (K)	mg/l	18 Aug. 01	16.50	7.70	22.20	21.64	
		28 Oct. 01	43.48	35.43	50.82	36.79	
		27 Jan. 02	21.85	33.69	41.84	32.79	
		27 Mar. 02	18.73	well damaged	37.36	23.88	
		27 Jul. 02	23.97	well damaged	39.67	30.79	80.64
Copper (Cu)	mg/l	18 Aug. 01	0.56	0.37	0.38	0.39	
		28 Oct. 01	0.20	0.26	0.11	0.38	
		27 Jan. 02	0.71	0.65	0.66	0.42	
		27 Mar. 02	0.54	well damaged	0.42	0.41	
		27 Jul. 02	0.15	well damaged	0.06	0.41	1.57
Cyanide (CN)	mg/l	18 Aug. 01	*	*	*	*	
		28 Oct. 01	*	*	*	*	
		27 Jan. 02	*	*	*	*	
		27 Mar. 02	*	*	*	*	
		27 Jul. 02	<0.1	well damaged	<0.1	<0.1	0.1

* not analysed

Table II.2 Data of deep well water analysis

Parameter	Unit	Date	ND1	ND2	ND3	ND4	ND5	ND6	ND7	ND8	ND9
Depth	m		250	200	252	200	200	252	276	255	260
pH		18 Aug. 01	7.3	7.8	7.8						
		28 Oct. 01	7.2	7.4	6.7	7.5	7.5				
		27 Jan. 02	7.1	7.1	6.8	7.3	7.2				
		27 Mar. 02	7.1	7.5	7.5	7.8	7.5	7.5	7.6	7.9	7.8
		27 Jul. 02	7.8	7.7	7.6	7.6	7.8	7.7	7.6	8.2	7.4
Electrical Conductivity	µS/cm	18 Aug. 01	512	496	504						
		28 Oct. 01	520	529	530	725	524				
		27 Jan. 02	542	524	545	729	528				
		27 Mar. 02	531	523	524	720	514	557	543	532	537
		27 Jul. 02	536	534	515	666	530	556	501	543	525
Temperature	°C	18 Aug. 01	*	*	*						
		28 Oct. 01	*	*	*	*	*				
		27 Jan. 02	34.0	33.5	37.0	31.0	35.0				
		27 Mar. 02	33.0	32.0	36.0	33.0	36.0	35.5	36.0	31.0	36.0
		27 Jul. 02	32.6	32.7	36.4	32.5	33.8	35.0	34.6	31.0	37.1
DO	mg/l	18 Aug. 01	*	*	*						
		28 Oct. 01	*	*	*	*	*				
		27 Jan. 02	1.0	1.3	4.1	4.8	2.0				
		27 Mar. 02	1.9	0.9	2.7	4.7	2.1	3.1	3.1	3.3	2.5
		27 Jul. 02	3.7	2.4	2.9	5.2	1.8	3.5	2.5	4.2	3.4
Total dissolved Solid	mg/l	18 Aug. 01	307.20	237.60	241.93						
(TDS)		28 Oct. 01	249.60	253.93	254.40	348.00	251.10				
		27 Jan. 02	260.20	251.50	261.60	349.90	253.40				
		27 Mar. 02	254.90	251.60	251.50	345.60	246.70	267.40	263.60	255.40	257.80
		27 Jul. 02	260.00	258.00	249.00	324.00	257.00	269.00	267.00	262.00	254.00
Total Hardness	mg/l	18 Aug. 01	894.00	64.00	62.00						
		28 Oct. 01	176.68	186.54	181.38	198.37	539.85				
		27 Jan. 02	121.82	120.03	131.24	155.28	160.91				
		27 Mar. 02	193.66	200.12	244.84	283.50	201.27	276.47	206.93	223.10	239.47
		27 Jul. 02	197.21	270.08	256.82	271.27	211.82	254.79	201.39	234.41	243.79
Sulfide	mg/l	18 Aug. 01	0.01	<0.01	0.03						
		28 Oct. 01	0.01	0.01	<0.01	0.01	0.02				
		27 Jan. 02	0.01	0.01	<0.01	0.02	0.02				
		27 Mar. 02	0.01	0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01
		27 Jul. 02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia Nitrogen	mg/l	18 Aug. 01	*	*	*						
		28 Oct. 01	*	*	*	*	*				
		27 Jan. 02	*	*	*	*	*				
		27 Mar. 02	0.21	0.31	0.18	0.39	0.37	0.68	0.52	0.52	0.87
		27 Jul. 02	0.14	0.15	0.15	0.22	0.09	0.06	0.17	0.04	0.16

Table II.2 Data of deep well water analysis (cont.)

Parameter	Unit	Date	ND1	ND2	ND3	ND4	ND5	ND6	ND7	ND8	ND9
Nitrate Nitrogen	mg/l	18 Aug. 01	250	200	252	200	200	262	276	255	250
		28 Oct. 01	*	*	*	*	*				
		27 Jan. 02	*	*	*	*	*				
		27 Mar. 02	1.7	1.5	1.9	1.5	1.6	1.6	1.6	1.6	1.4
		27 Jul. 02	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mercury (Hg)	µg/l	18 Aug. 01	<1.0	<1.0	<1.0						
		28 Oct. 01	<1.0	<1.0	<1.0	<1.0	<1.0				
		27 Jan. 02	<1.0	<1.0	<1.0	<1.0	<1.0				
		27 Mar. 02	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		27 Jul. 02	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Chromium (Cr)	mg/l	18 Aug. 01	0.08	0.19	0.20						
		28 Oct. 01	0.11	0.10	0.09	0.09	0.09				
		27 Jan. 02	0.13	0.15	0.11	0.08	0.06				
		27 Mar. 02	0.15	0.10	0.09	0.16	0.06	0.18	0.17	0.06	0.14
		27 Jul. 02	0.13	0.08	<0.05	0.27	<0.05	0.15	0.13	0.08	0.12
Cadmium (Cd)	mg/l	18 Aug. 01	<0.02	<0.02	<0.02						
		28 Oct. 01	<0.02	<0.02	<0.02	<0.02	<0.02				
		27 Jan. 02	<0.02	<0.02	<0.02	<0.02	<0.02				
		27 Mar. 02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 Jul. 02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Lead (Pb)	mg/l	18 Aug. 01	0.25	0.30	<0.1						
		28 Oct. 01	<0.1	0.04	<0.1	0.22	0.13				
		27 Jan. 02	0.19	0.25	<0.1	0.18	0.13				
		27 Mar. 02	0.19	0.08	0.12	0.15	<0.1	0.13	0.17	0.10	0.052
		27 Jul. 02	0.30	0.26	0.15	0.33	0.24	0.26	0.28	0.22	0.184
Manganese (Mn)	mg/l	18 Aug. 01	0.30	0.40	0.33						
		28 Oct. 01	0.05	0.03	0.34	0.05	0.28				
		27 Jan. 02	0.08	0.09	0.05	0.10	0.04				
		27 Mar. 02	0.11	0.08	0.12	0.03	0.07	0.04	0.05	<0.01	<0.01
		27 Jul. 02	0.01	0.01	0.05	0.05	0.05	0.03	0.04	<0.01	<0.01
Total Iron (Fe)	mg/l	18 Aug. 01	<0.1	<0.1	<0.1						
		28 Oct. 01	<0.1	<0.1	<0.1	<0.1	<0.1				
		27 Jan. 02	<0.1	<0.1	<0.1	<0.1	<0.1				
		27 Mar. 02	<0.1	<0.1	0.12	0.52	0.26	<0.1	<0.1	<0.1	<0.1
		27 Jul. 02	<0.1	<0.1	0.10	0.10	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel (Ni)	mg/l	18 Aug. 01	<0.01	<0.01	<0.01						
		28 Oct. 01	<0.01	<0.01	<0.01	<0.01	<0.01				
		27 Jan. 02	<0.01	<0.01	<0.01	<0.01	<0.01				
		27 Mar. 02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
		27 Jul. 02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table II.2 Data of deep well water analysis (cont.)

Parameter	Unit	Date	ND1	ND2	ND3	ND4	ND5	ND6	ND7	ND8	ND9
Zinc (Zn)	mg/l	18 Aug. 01	250	203	252	203	203	252	276	255	250
		28 Oct. 01	0.72	0.04	0.08	0.54	0.40				
		27 Jan. 02	0.40	0.03	0.05	0.42	0.07				
		27 Mar. 02	0.43	0.02	0.04	0.65	0.08	0.11	0.14	0.07	0.32
		27 Jul. 02	0.52	<0.02	<0.02	0.34	0.06	0.07	0.13	0.02	0.22
Arsenic (As)	µg/l	18 Aug. 01	4.59	9.60	<3.0						
		28 Oct. 01	3.38	<3.0	<3.0	5.64	<3.0				
		27 Jan. 02	<3.0	<3.0	<3.0	7.32	4.08				
		27 Mar. 02	3.44	<3.0	<3.0	5.66	<3.0	4.44	<3.0	3.52	3.33
		27 Jul. 02	<3.0	<3.0	<3.0	6.14	<3.0	9.43	3.08	<3.0	7.45
Magnesium (Mg)	mg/l	18 Aug. 01	10.6	9.9	10.0						
		28 Oct. 01	9.8	9.4	9.3	12.7	96.0				
		27 Jan. 02	10.2	10.0	8.9	13.3	10.1				
		27 Mar. 02	7.6	8.2	7.4	12.5	7.9	6.7	7.3	8.5	9.2
		27 Jul. 02	8.6	9.5	8.7	13.5	8.7	7.6	8.4	8.3	7.9
Calcium(Ca)	mg/l	18 Aug. 01	49.10	43.20	45.00						
		28 Oct. 01	54.60	59.20	57.30	58.60	58.50				
		27 Jan. 02	32.00	31.60	37.90	40.30	47.60				
		27 Mar. 02	65.00	93.60	85.60	92.90	67.55	99.60	70.80	75.30	80.70
		27 Jul. 02	64.78	92.45	88.40	88.45	70.40	89.45	66.78	80.15	84.56
Sodium (Na)	mg/l	18 Aug. 01	78.10	81.30	74.20						
		28 Oct. 01	60.08	91.55	89.50	97.80	77.80				
		27 Jan. 02	95.10	90.00	82.00	98.00	87.60				
		27 Mar. 02	75.10	86.00	91.30	107.70	75.90	83.90	112.30	77.80	72.70
		27 Jul. 02	84.31	91.63	93.45	99.40	83.15	82.45	101.45	84.65	75.94
Potassium(K)	mg/l	18 Aug. 01	3.27	3.81	3.54						
		28 Oct. 01	10.30	3.27	3.69	4.81	6.70				
		27 Jan. 02	2.93	3.27	3.24	2.95	2.40				
		27 Mar. 02	1.20	3.06	2.95	3.60	3.21	3.08	2.57	3.50	3.86
		27 Jul. 02	2.84	3.17	3.14	3.64	2.94	3.14	2.94	3.45	3.76
Copper(Cu)	mg/l	18 Aug. 01	0.13	0.09	0.09						
		28 Oct. 01	0.14	0.16	0.16	0.13	0.13				
		27 Jan. 02	0.10	0.08	0.03	0.12	0.13				
		27 Mar. 02	0.06	0.09	0.05	0.09	0.09	0.65	0.09	0.11	0.11
		27 Jul. 02	<0.05	0.06	0.17	0.06	0.32	0.08	<0.05	<0.05	<0.05
Cyanide(CN)	mg/l	18 Aug. 01	*	*	*						
		28 Oct. 01	*	*	*	*	*				
		27 Jan. 02	*	*	*	*	*				
		27 Mar. 02	*	*	*	*	*	*	*	*	*
		27 Jul. 02	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

* not analysed

Table II.3 Data of surface water analysis

Parameter	Unit	Date	Borro pit	Pond	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Ha Ro
			NS1	NS2	NS3	NS4	NS5	NS6	NS7
Depth	m		10	4	2	2	2	2	2
pH	-	18 Aug. 01	7.8	7.5	7.6	7.0	7.2	7.1	7.0
		28 Oct. 01	7.9	7.5	7.6	7.0	7.2	7.1	6.9
		27 Jan. 02	8.0	7.6	7.7	7.1	7.3	7.2	6.7
		27 Mar. 02	8.0	7.6	7.7	7.1	7.3	7.2	7.5
		27 Jul. 02	8.0	7.6	7.6	7.0	7.2	7.5	7.5
Electrical Conductivity	µS/cm	18 Aug. 01	9850	2480	351	495	345	455	375
		28 Oct. 01	10500	2360	385	472	376	475	357
		27 Jan. 02	11050	2780	450	515	445	584	525
		27 Mar. 02	11270	2630	471	504	462	645	485
		27 Jul. 02	11280	2820	752	658	712	382	453
Temperature	°C	18 Aug. 01	33.5	33.0	34.0	32.5	32.0	33.0	30.0
		28 Oct. 01	32.5	33.5	33.5	33.0	31.5	32.0	30.5
		27 Jan. 02	32.0	31.0	32.0	31.0	30.0	30.0	29.0
		27 Mar. 02	34.0	31.5	34.0	32.5	32.0	32.0	34.0
		27 Jul. 02	31.0	32.0	31.5	33.0	32.5	32.1	31.9
DO	mg/l	18 Aug. 01	*	*	*	*	*	*	*
		28 Oct. 01	*	*	*	*	*	*	*
		27 Jan. 02	6.5	4.2	3.9	3.7	3.5	3.4	1.1
		27 Mar. 02	7.0	3.1	4.8	2.7	3.0	3.2	6.8
		27 Jul. 02	5.6	3.9	3.5	3.6	2.8	3.1	3.5
Total Dissolved Solid **(TDS)**	mg/l	18 Aug. 01	5102.00	1289.60	168.50	237.60	165.80	216	180
		28 Oct. 01	5460.00	1227.20	184.80	226.60	180.50	228.00	171.40
		27 Jan. 02	5746.00	1445.60	216.00	247.30	213.60	280.30	252.00
		27 Mar. 02	5880.40	1362.40	226.10	241.90	221.80	309.60	232.80
		27 Jul. 02	6665.60	1466.40	361.00	315.80	341.80	183.40	217.40
Total Hardness	mg/l	18 Aug. 01	2102.14	717.05	287.94	332.79	307.14	362.64	300.14
		28 Oct. 01	1933.83	769.35	260.42	330.87	287.41	318.66	291.74
		27 Jan. 02	1935.12	617.41	227.14	268.84	279.21	265.69	221.21
		27 Mar. 02	1853.17	709.66	215.74	265.10	246.47	293.31	323.25
		27 Jul. 02	1884.29	751.62	232.71	252.91	286.22	293.54	280.30
Sulfide	mg/l	18 Aug. 01	0.038	0.013	<0.01	<0.01	<0.01	0.16	<0.01
		28 Oct. 01	0.036	0.016	<0.01	<0.01	<0.01	0.18	<0.01
		27 Jan. 02	0.042	0.021	<0.01	<0.01	<0.01	0.21	<0.01
		27 Mar. 02	<0.01	0.023	<0.01	<0.01	<0.01	0.35	0.013
		27 Jul. 02	0.058	0.034	<0.01	<0.01	<0.01	0.47	0.029
Ammonia Nitrogen	mg/l	18 Aug. 01	*	*	*	*	*	*	*
		28 Oct. 01	*	*	*	*	*	*	*
		27 Jan. 02	*	*	*	*	*	*	*
		27 Mar. 02	2.31	1.53	0.4	0.62	0.48	1.03	1.67
		27 Jul. 02	1.89	1.47	0.89	0.58	0.35	0.27	0.35

Table II.3 Data of surface water analysis (cont.)

Parameter	Unit	Date	Borro pit	Pond	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Ha Ro
			NS1	NS2	NS3	NS4	NS5	NS6	NS7
Nitrate Nitrogen	mg/l	18 Aug. 01	-	-	-	-	-	-	-
		28 Oct. 01	-	-	-	-	-	-	-
		27 Jan. 02	-	-	-	-	-	-	-
		27 Mar. 02	1.5	1.8	0.3	1.4	0.8	0	1.4
		27 Jul. 02	1.4	1.7	0.5	1.3	0.6	0.4	0.7
Mercury (Hg)	µg/l	18 Aug. 01	1.32	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		28 Oct. 01	1.25	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		27 Jan. 02	1.46	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		27 Mar. 02	1.13	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
		27 Jul. 02	1.13	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Chromium (Cr)	mg/l	18 Aug. 01	0.22	0.24	0.22	0.20	0.20	0.21	0.07
		28 Oct. 01	0.22	0.36	0.34	0.19	0.21	0.21	0.09
		27 Jan. 02	0.30	0.35	0.22	0.17	0.20	0.23	0.14
		27 Mar. 02	0.18	0.21	0.20	0.20	0.19	0.17	0.17
		27 Jul. 02	0.10	0.18	0.20	0.19	0.17	0.15	0.18
Cadmium (Cd)	mg/l	18 Aug. 01	<0.02	<0.02	<0.02	<0.02	<0.5	<0.02	<0.02
		28 Oct. 01	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 Jan. 02	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 Mar. 02	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 **Jul. 02**	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Lead (Pb)	mg/l	18 **Aug. 01**	0.29	0.13	<0.1	<0.1	<0.1	<0.1	<0.1
		28 Oct. 01	0.30	<0.1	0.10	<0.1	<0.1	<0.1	<0.1
		27 Jan. 02	0.28	<0.1	<0.1	<0.1	<0.1	<0.1	0.11
		27 Mar. 02	0.29	<0.1	<0.1	<0.1	<0.1	<0.1	0.14
		27 Jul. 02	0.29	<0.1	<0.1	<0.1	<0.1	<0.1	0.14
Manganese (Mn)	mg/l	18 Aug. 01	0.64	0.21	0.08	0.10	0.08	0.05	0.29
		28 Oct. 01	0.56	0.16	0.69	0.10	0.07	0.06	0.33
		27 Jan. 02	0.67	0.20	0.58	0.09	0.08	0.09	0.50
		27 Mar. 02	0.53	0.17	0.06	0.10	0.08	0.08	0.32
		27 Jul. 02	0.58	0.16	0.07	0.08	0.06	0.09	0.32
Total Iron (Fe)	mg/l	18 Aug. 01	0.77	0.35	0.72	0.74	0.62	0.58	1.45
		28 Oct. 01	0.34	0.40	0.56	0.49	0.57	0.79	2.30
		27 Jan. 02	0.29	0.37	0.66	0.65	0.69	0.84	0.60
		27 **Mar. 02**	0.31	0.33	0.59	0.50	0.50	0.63	1.33
		27 Jul. 02	0.45	0.26	0.54	0.71	0.73	0.74	**1.06**
Nickel (Ni)	mg/l	18 **Aug. 01**	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
		28 Oct. 01	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
		27 **Jan. 02**	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
		27 **Mar. 02**	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
		27 **Jul. 02**	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.04

Table II.3 Data of surface water analysis (cont.)

Parameter	Unit	Date	Borro pit	Pond	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Na Mon	Khong Ha Ro:
			NS1	NS2	NS3	NS4	NS5	NS6	NS7
Zinc (Zn)	mg/l	18 Aug. 01	0.02	<0.02	0.02	<0.02	0.02	<0.02	<0.02
		28 Oct. 01	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02
		27 Jan. 02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 Mar. 02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
		27 Jul. 02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Arsenic (As)	µg/l	18 Aug. 01	3.50	5.69	<3	<3	9.34	<3	4.83
		28 Oct. 01	2.59	3.28	2.30	2.00	10.10	<3	3.31
		27 Jan. 02	3.28	4.97	<3	5.00	12.00	3.00	3.62
		27 Mar. 02	9.23	6.99	<3	3.60	10.50	4.31	6.13
		27 Jul. 02	4.35	5.84	<3	7.00	11.30	4.23	8.62
Magnesium(Mg)	mg/l	18 Aug. 01	237.9	90.5	20.9	19.4	15.4	25.4	12.9
		28 Oct. 01	224.8	181.7	18.7	20.7	17.6	17.6	11.4
		27 Jan. 02	230.7	72.6	15.4	14.9	20.6	18.4	15.6
		27 Mar. 02	226.2	65.1	11.4	13.5	11.7	16.6	11.9
		27 Jul. 02	235.1	91.4	13.8	15.1	18.4	15.9	13.7
Calcium(Ca)	mg/l	18 Aug. 01	450.70	138.40	80.90	101.30	97.60	103.40	110.90
		28 Oct. 01	404.90	140.95	73.00	98.40	86.10	98.60	98.00
		27 Jan. 02	395.70	127.90	65.00	83.10	77.90	76.10	82.90
		27 Mar. 02	370.30	144.30	67.00	83.90	79.40	88.90	109.80
		27 Jul. 02	368.15	150.75	70.45	76.40	84.31	90.14	89.65
Sodium (Na)	mg/l	18 Aug. 01	297.84	295.30	25.93	53.90	28.30	76.93	28.60
		28 Oct. 01	283.72	273.10	40.30	63.20	34.60	64.31	25.53
		27 Jan. 02	304.57	288.00	39.70	48.90	23.00	53.04	45.10
		27 Mar. 02	280.30	230.43	35.93	41.01	32.51	47.99	39.01
		27 Jul. 02	293.17	250.37	37.24	38.49	30.46	50.17	43.38
Potassium(K)	mg/l	18 Aug. 01	60.83	34.85	4.63	4.39	4.78	4.65	5.21
		28 Oct. 01	59.85	33.21	4.82	4.78	4.92	4.86	5.09
		27 Jan. 02	61.09	34.43	5.65	5.83	5.48	5.42	5.53
		27 Mar. 02	62.78	35.57	5.57	5.34	5.53	5.53	6.21
		27 Jul. 02	69.82	37.62	6.64	5.97	5.84	5.79	6.34
Copper(Cu)	mg/l	18 Aug. 01	0.09	0.08	0.09	0.09	0.07	0.06	0.06
		28 Oct. 01	0.05	0.07	0.09	0.09	0.06	0.06	0.06
		27 Jan. 02	0.06	0.09	0.10	0.08	0.09	0.05	0.08
		27 Mar. 02	0.06	0.09	0.09	0.09	0.09	0.09	0.07
		27 Jul. 02	0.04	0.08	0.06	0.08	0.07	<0.05	<0.05
Cyanide(CN)	mg/l	18 Aug. 01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
		28 Oct. 01	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
		27 Jan. 02	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
		27 Mar. 02	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
		27 Jul. 02	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

* not analysed

APPENDIX III

CONTOUR LINE OF CHEMICAL ANALYSIS: SURFACE WATER AND SUBSURFACE WATER

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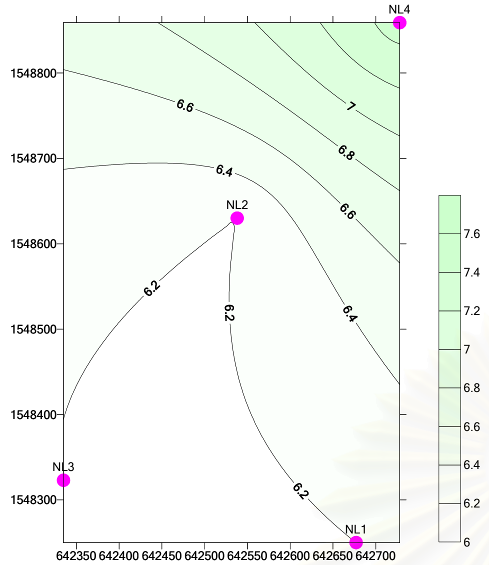
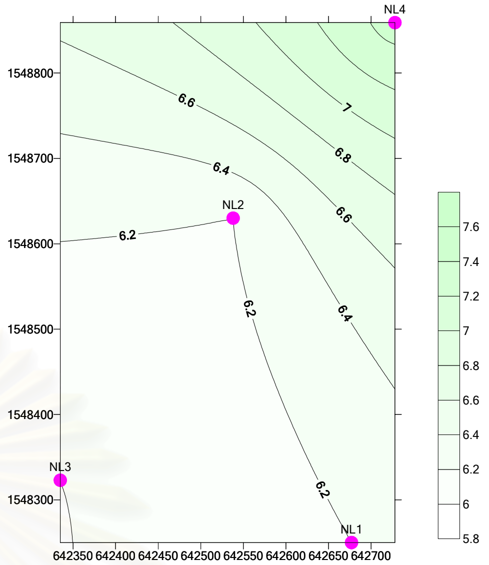
Appendix III.1 Contour line of chemical analysis: shallow subsurface water

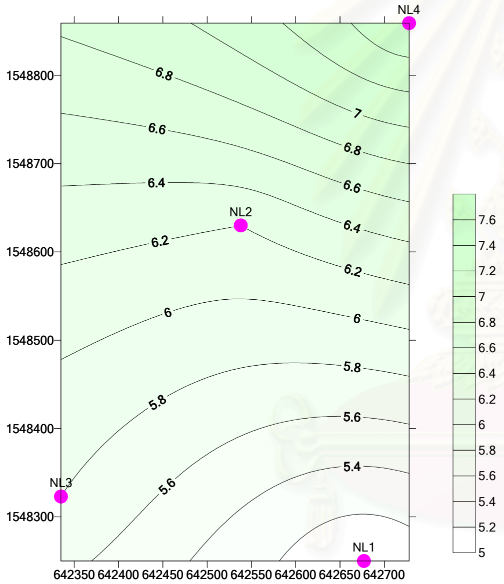
pH (18 Aug.01)



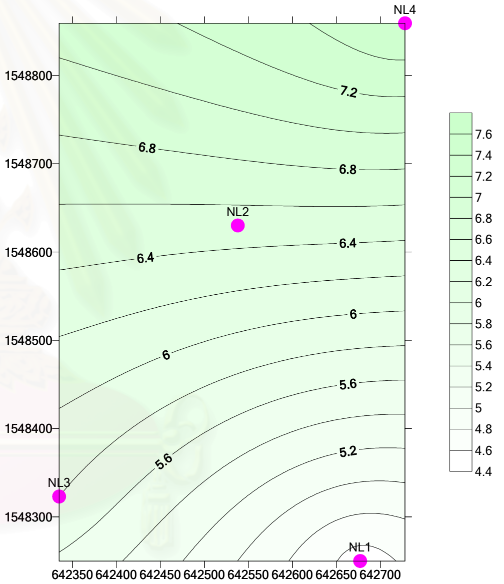
pH (28 Oct. 01)



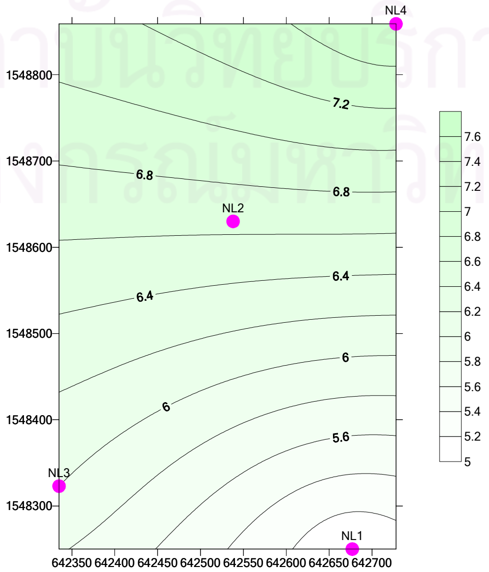
pH (27 Jan. 02)



pH (27 Mar. 02)



pH (27 Jul. 02)



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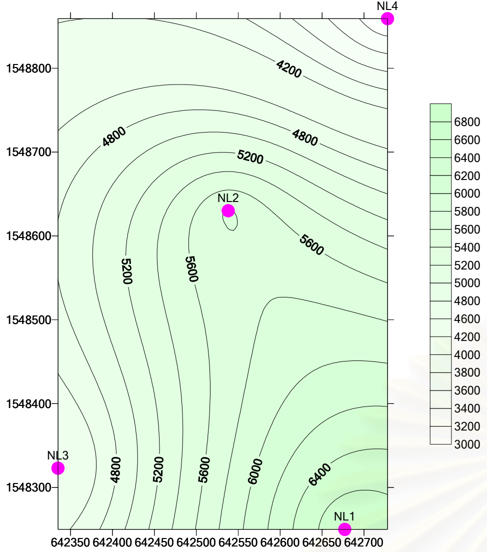
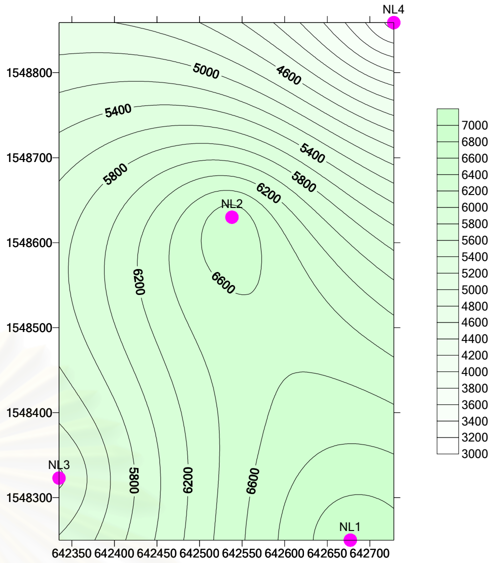
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

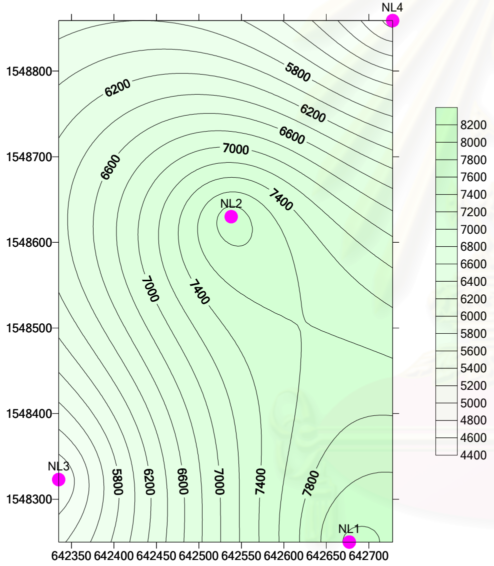
Electrical Conductivity (18 Aug. 01)



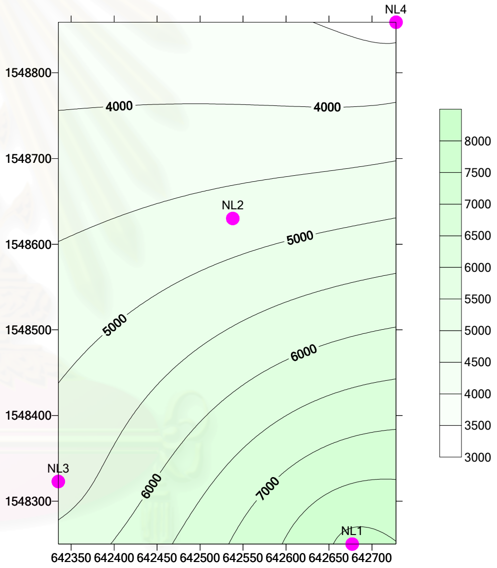
Electrical Conductivity (28 Oct. 01)



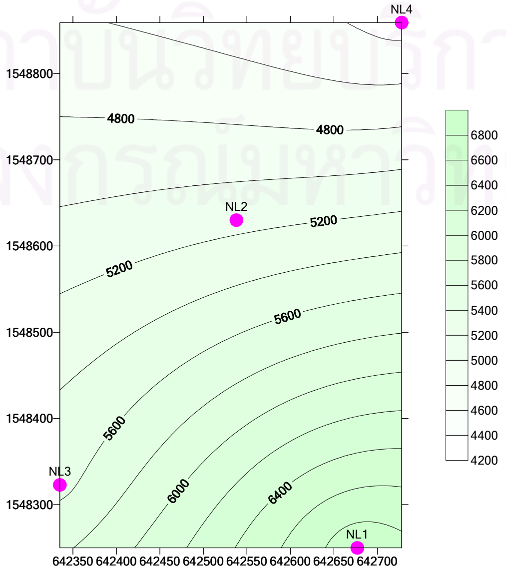
Electrical Conductivity (27 Jan. 02)



Electrical Conductivity (27 Mar. 02)



Electrical Conductivity (27 Jul. 02)



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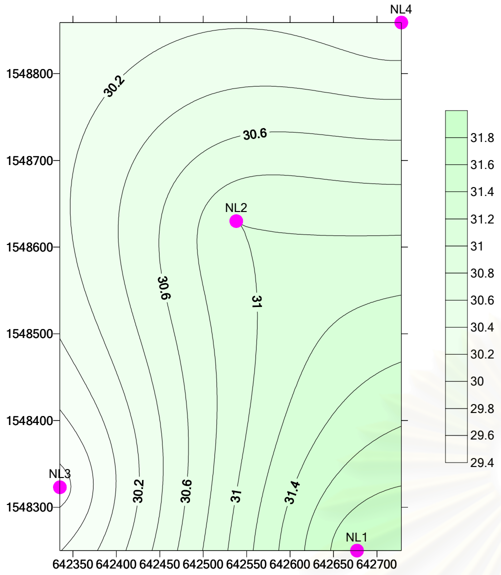
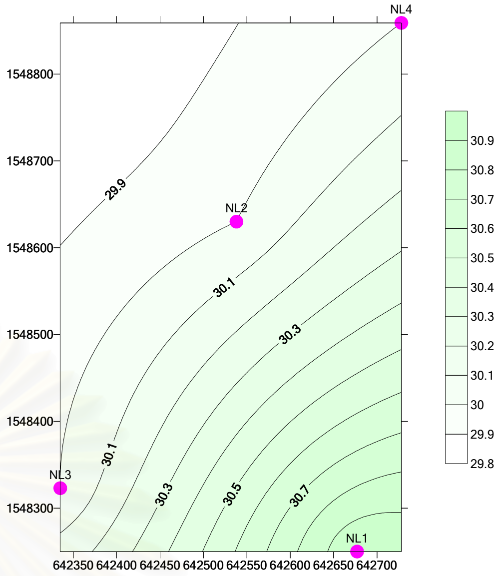
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

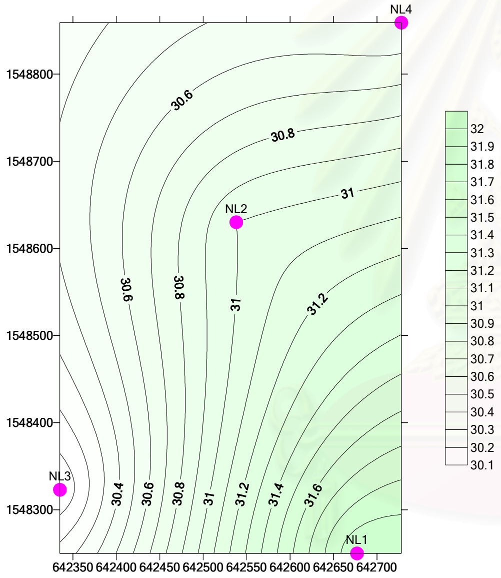
Temperature (18 Aug. 01)



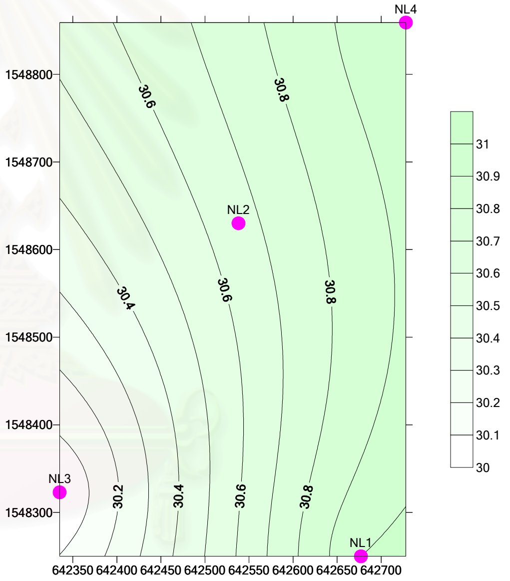
Temperature (28 Oct. 01)



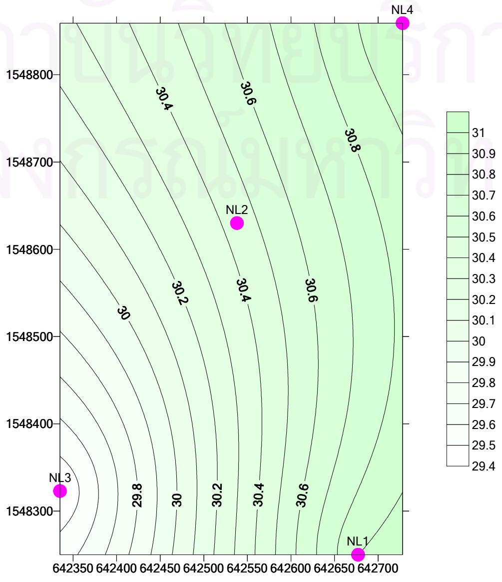
Temperature (27 Jan. 02)



Temperature (27 Mar. 02)



Temperature (27 Jul. 02)



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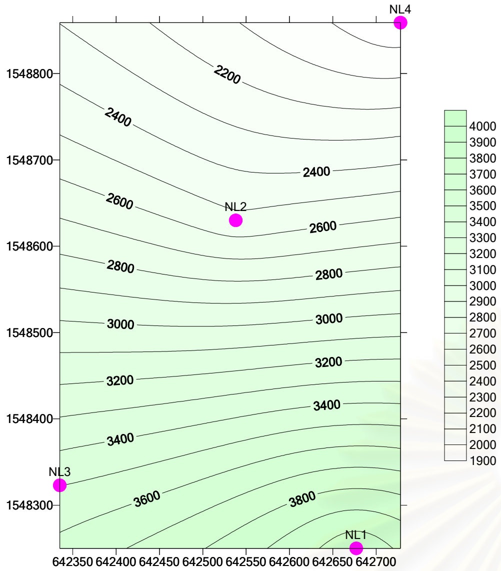
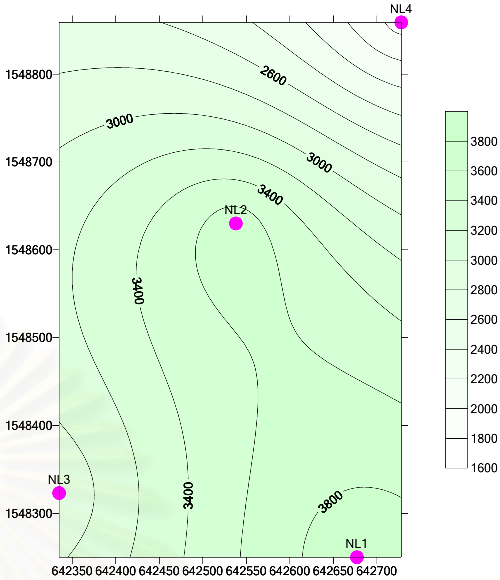
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

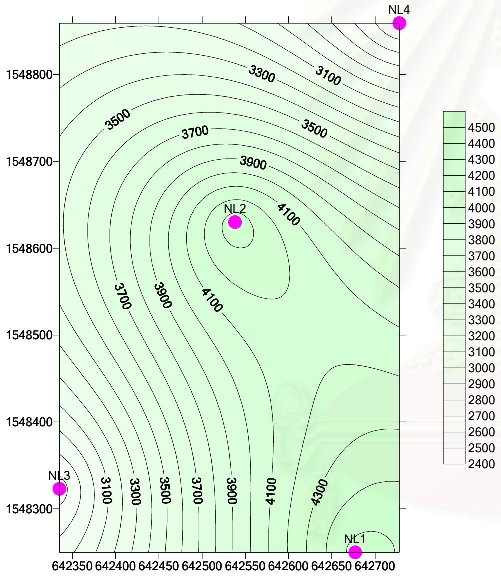
Total Dissolved Solid (18 Aug. 01)



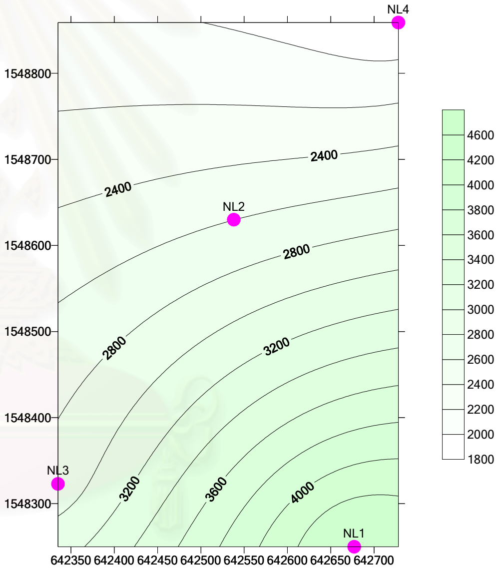
Total Dissolved Solid (28 Oct. 01)



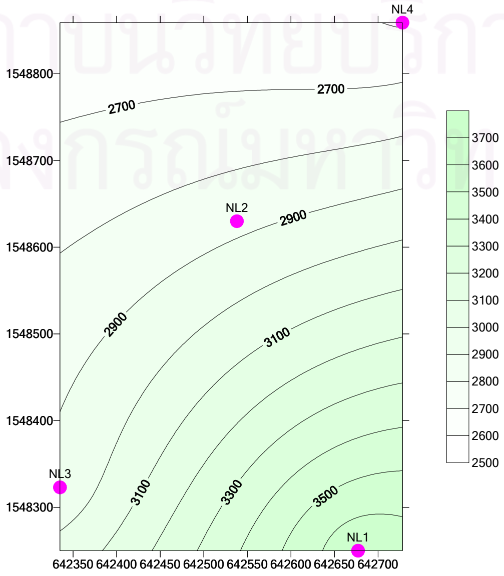
Total Dissolved Solid (27 Jan. 02)



Total Dissolved Solid (27 Mar. 02)



Total Dissolved Solid (27 Jul. 02)



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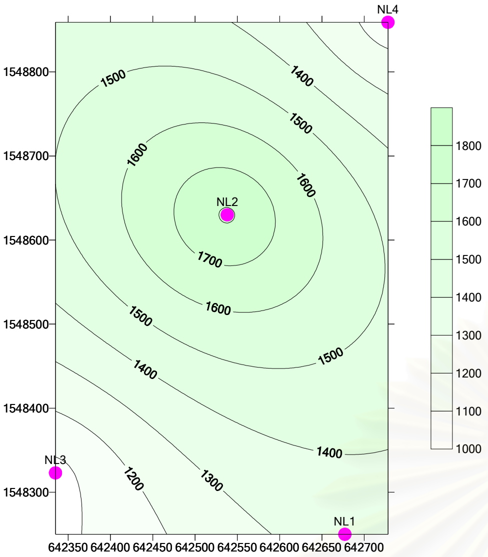
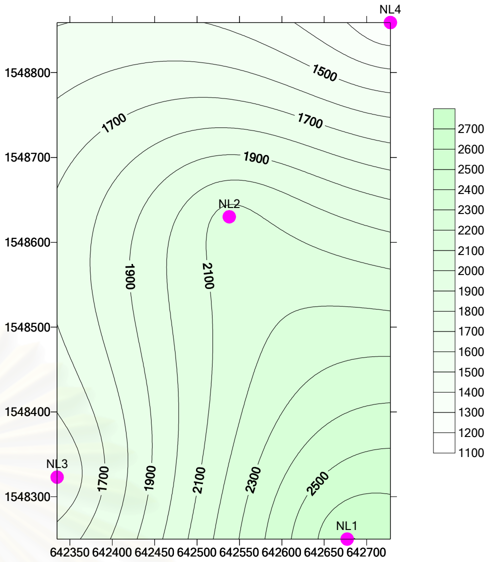
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

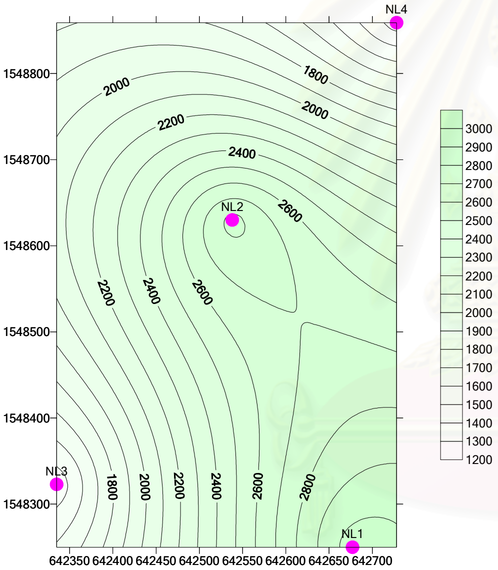
Total Hardness (18 Aug. 01)



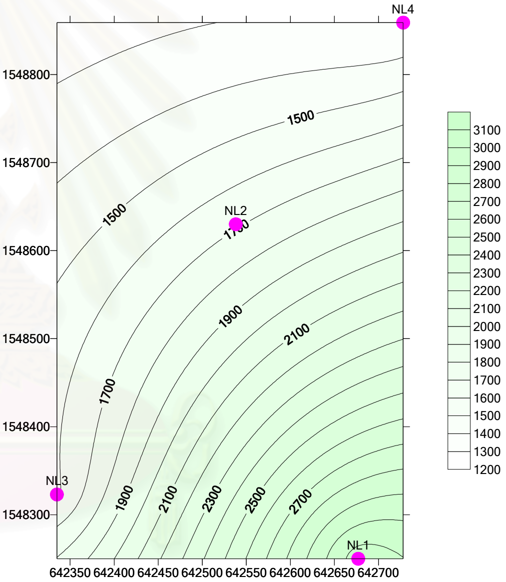
Total Hardness (28 Oct. 01)



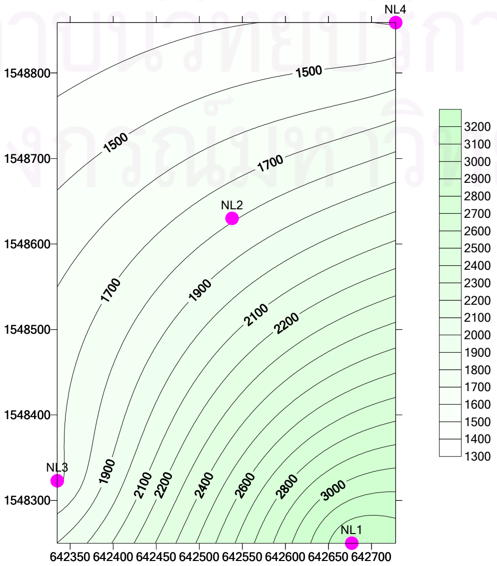
Total Hardness (27 Jan. 02)



Total Hardness (27 Mar. 02)



Total Hardness (27 Jul. 02)



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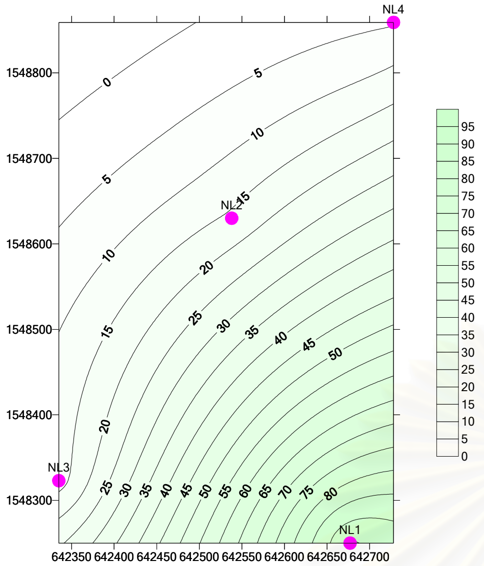
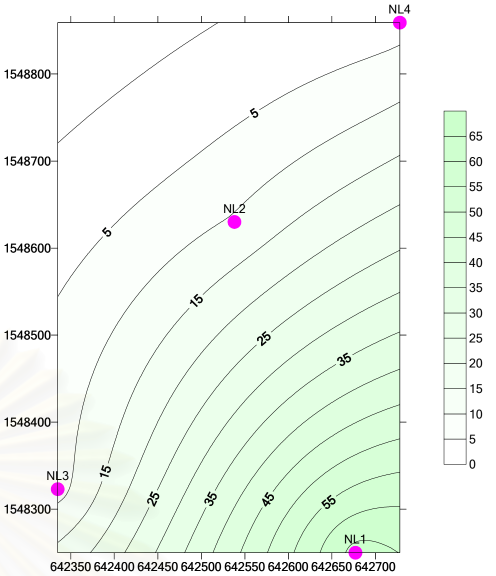
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

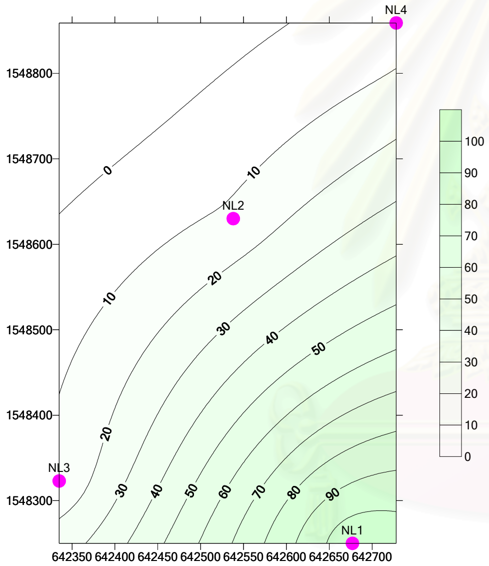
Ammonia Nitrogen (18 Aug. 01)



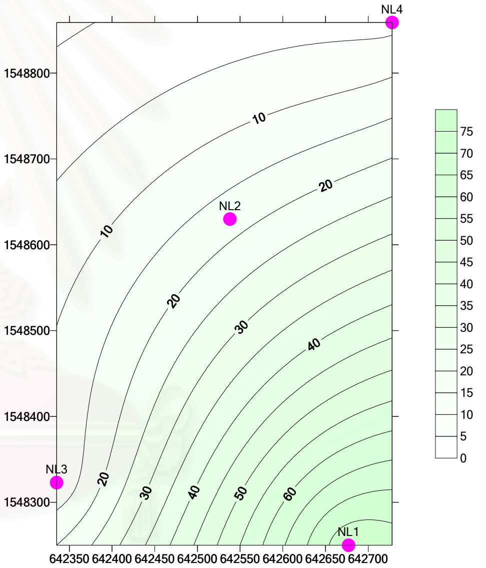
Ammonia Nitrogen (28 Oct. 01)



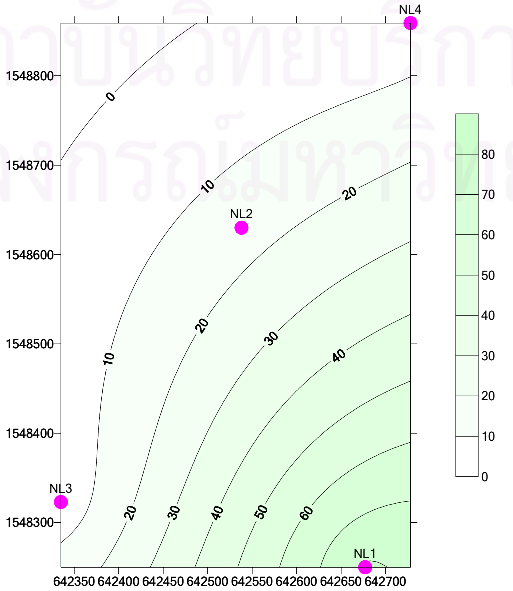
Ammonia Nitrogen (27 Jan. 02)



Ammonia Nitrogen (27 Mar. 02)



Ammonia Nitrogen (27 Jul. 02)



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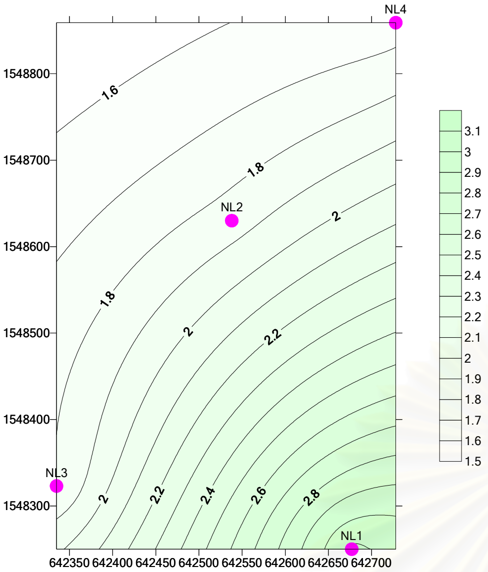
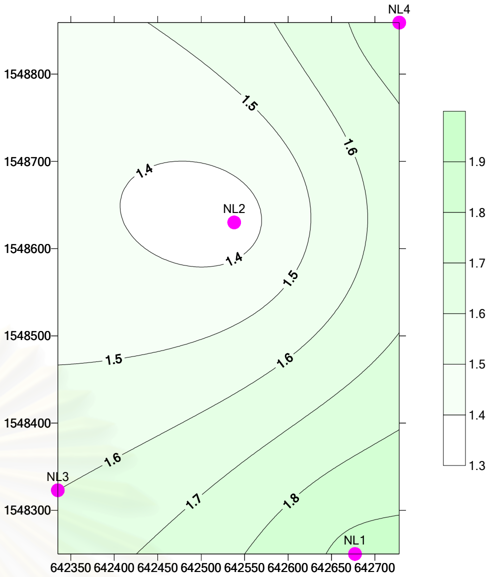
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

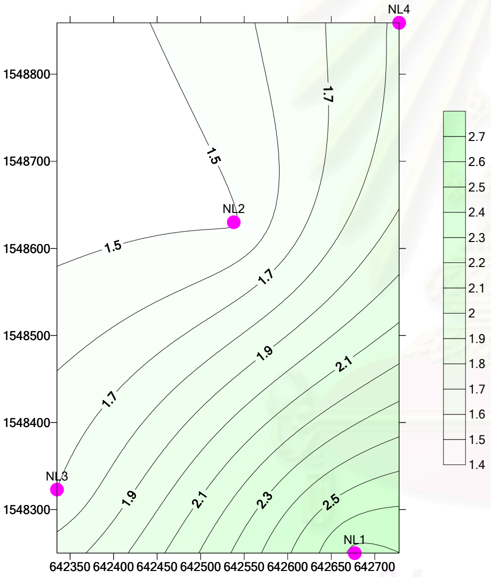
Nitrate Nitrogen (18 Aug. 01)



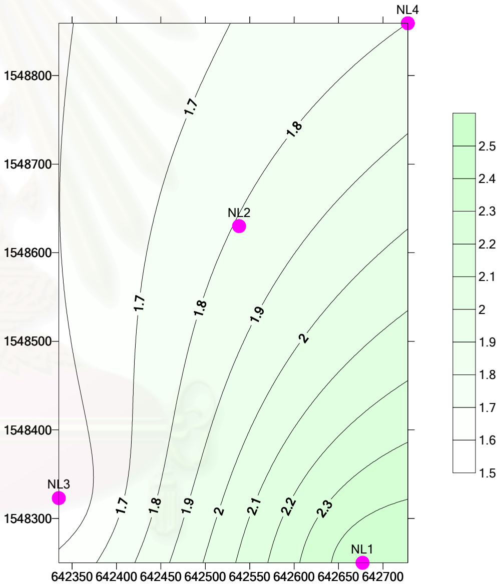
Nitrate Nitrogen (28 Oct. 01)



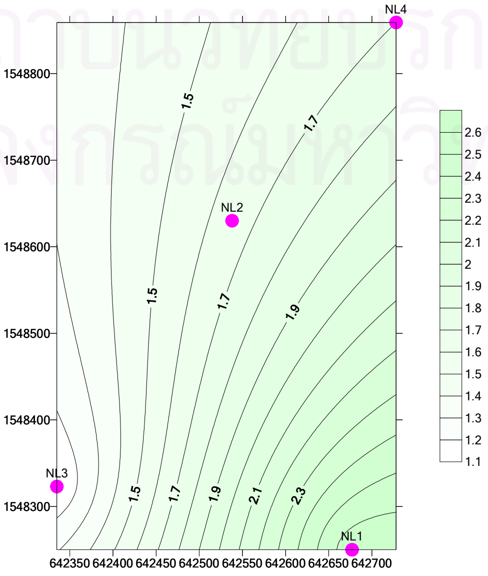
Nitrate Nitrogen (27 Jan. 02)



Nitrate Nitrogen (27 Mar. 02)



Nitrate Nitrogen (27 Jul. 02)



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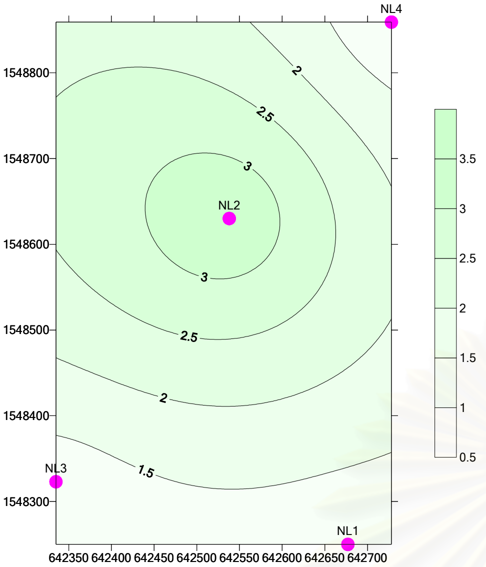
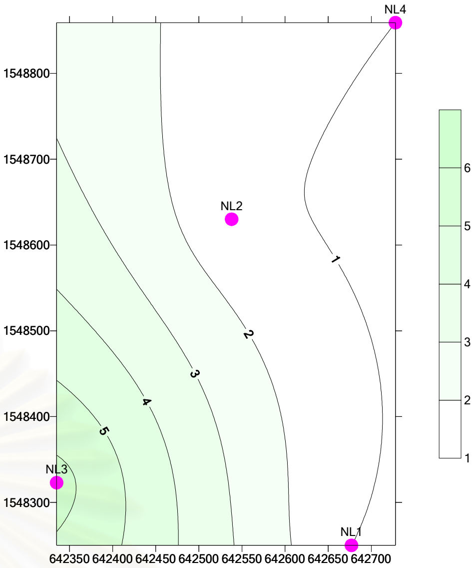
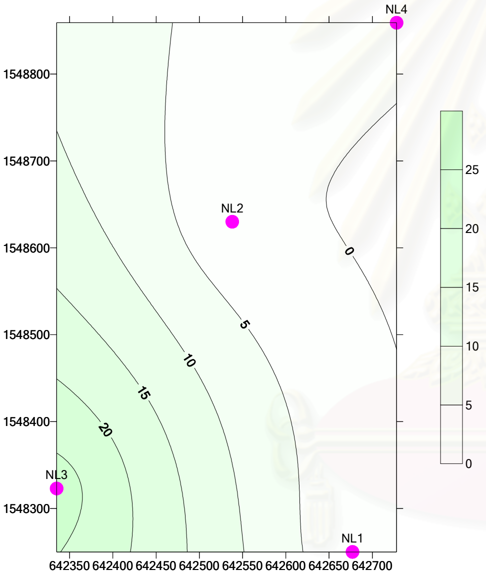
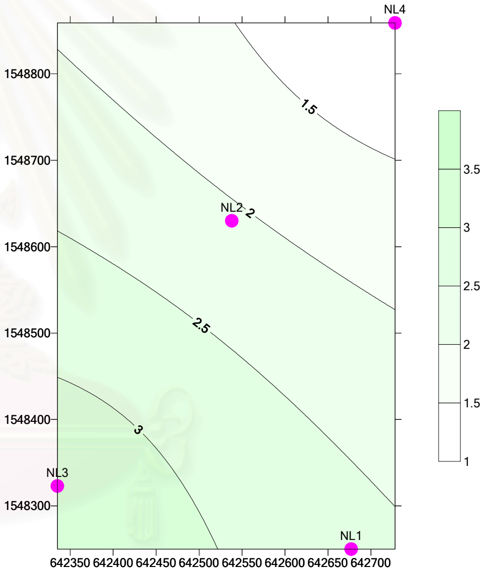
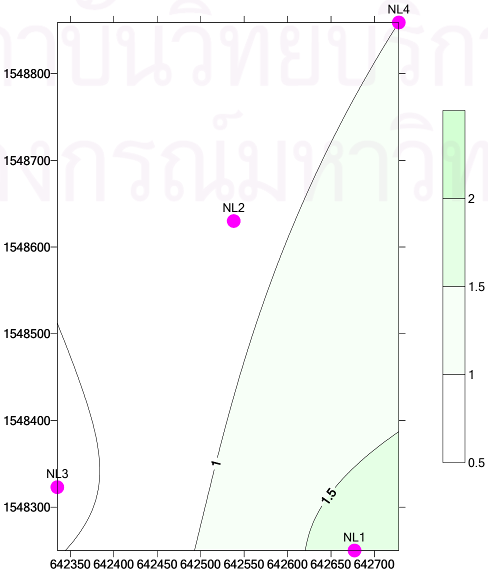
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)


Mercury (18 Aug. 01)


Mercury (28 Oct. 01)


Mercury (27 Jan. 02)


Mercury (27 Mar. 02)


Mercury (27 Jul. 02)

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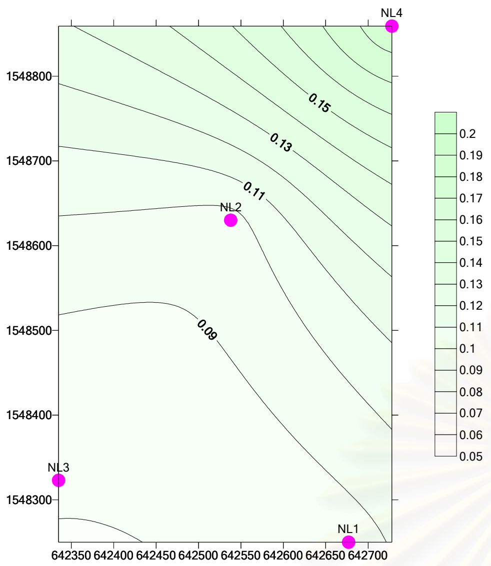
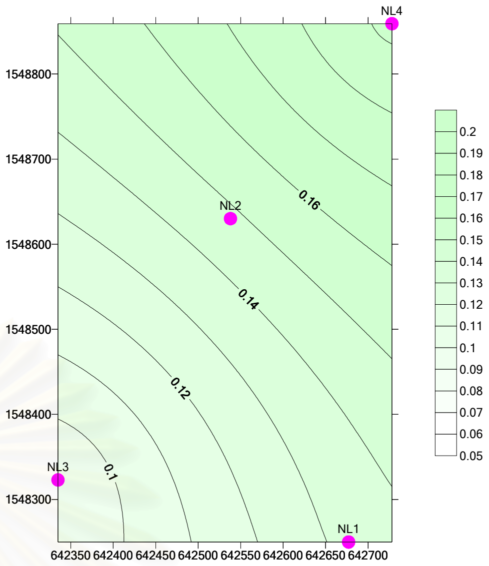
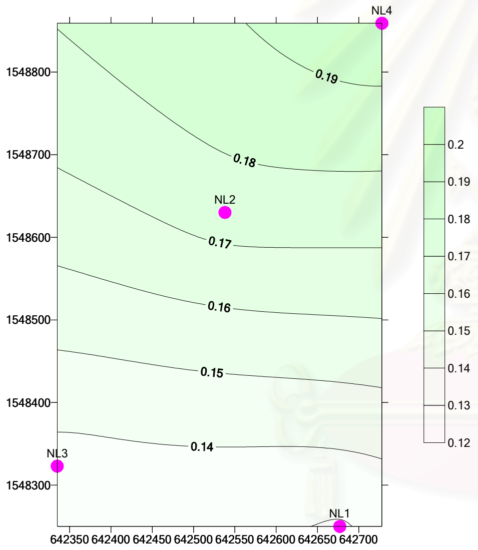
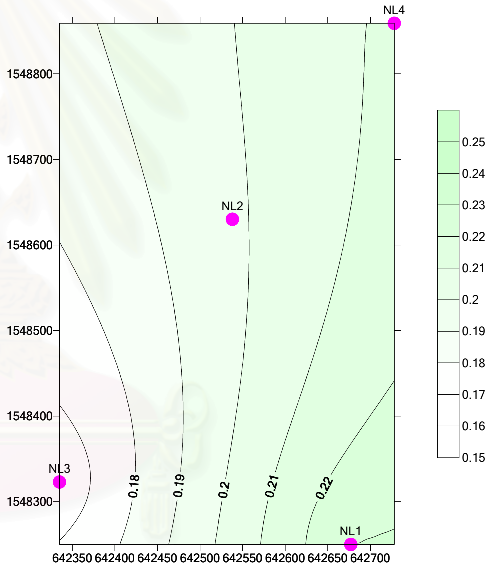
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)


Total Chromium (18 Aug. 01)

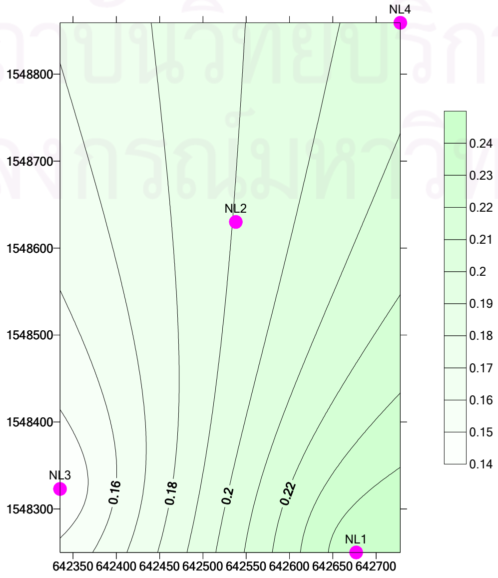

Total Chromium (28 Oct. 01)


Total Chromium (27 Jan. 02)

Total Chromium (27 Mar. 02)



Total Chromium (27 Jul .02)



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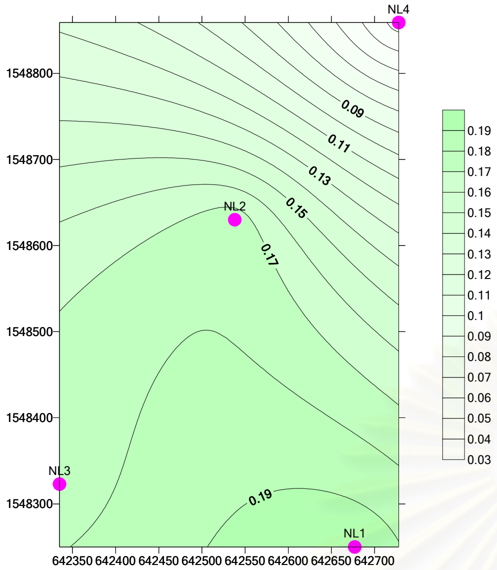
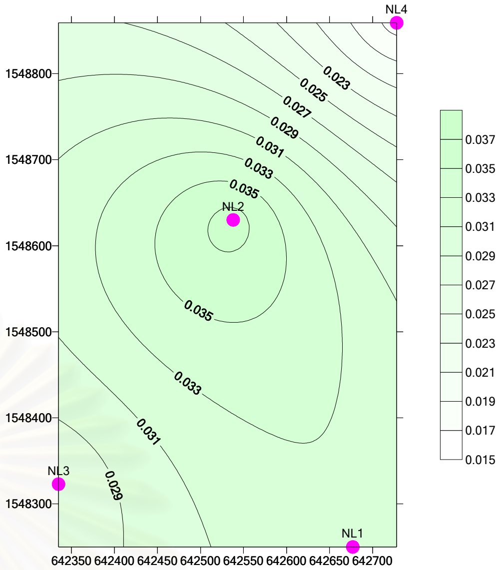
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

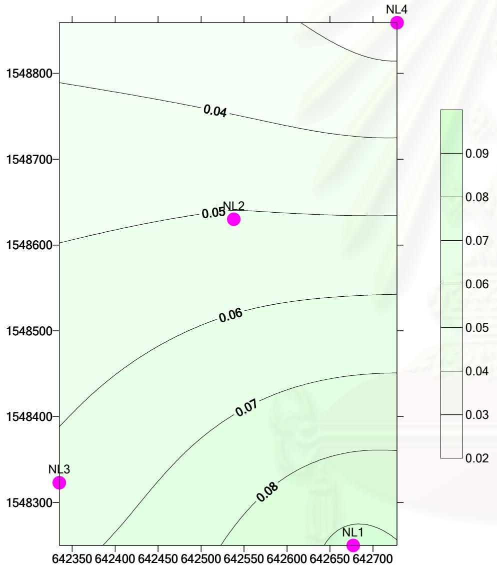
Cadmium (18 Aug. 01)



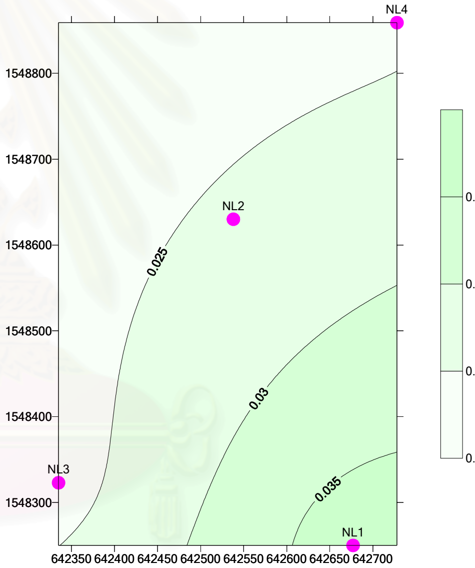
Cadmium (28 Oct. 01)



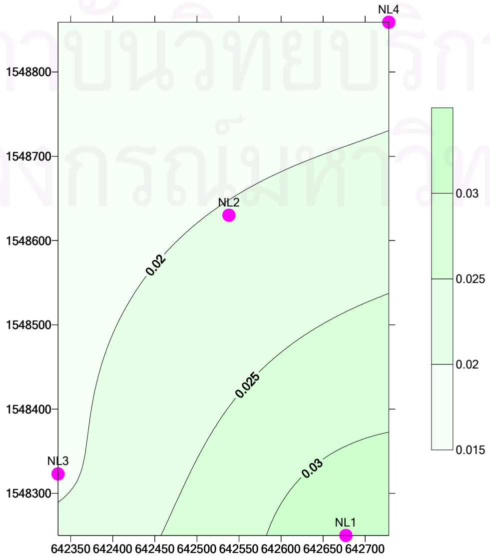
Cadmium (27 Jan. 02)



Cadmium (27 Mar. 02)



Cadmium (27 Jul. 02)



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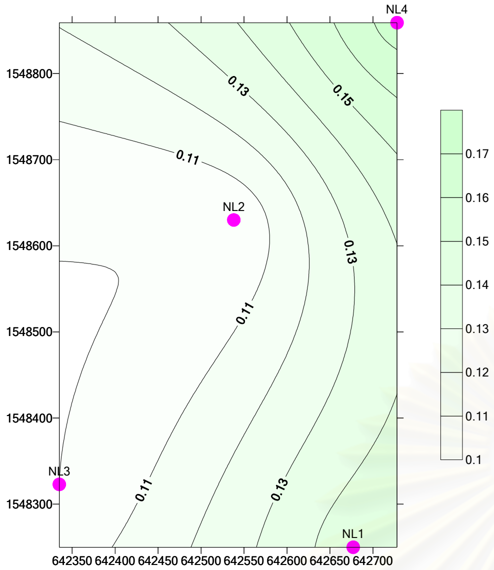
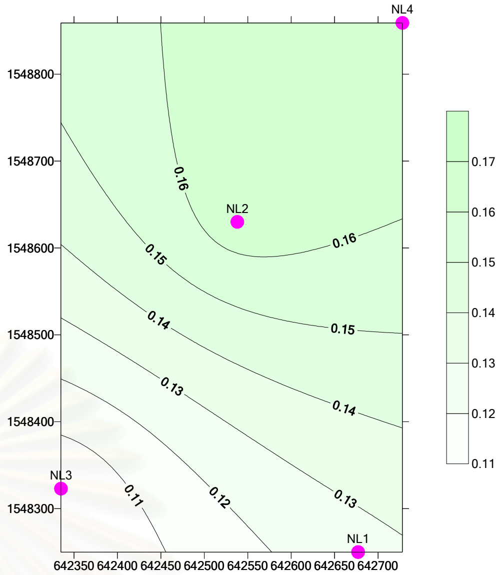
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

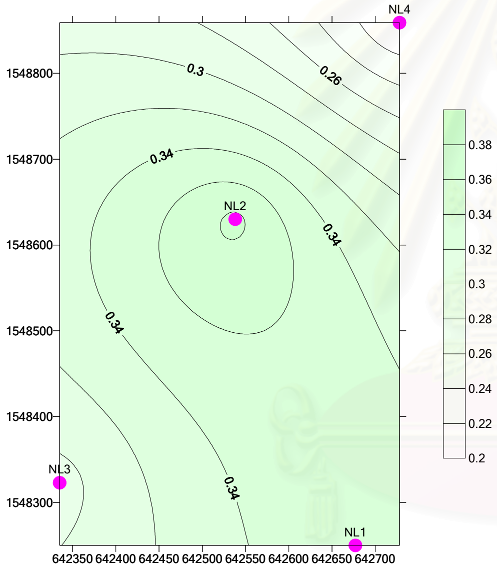
Lead (18 Aug. 01)



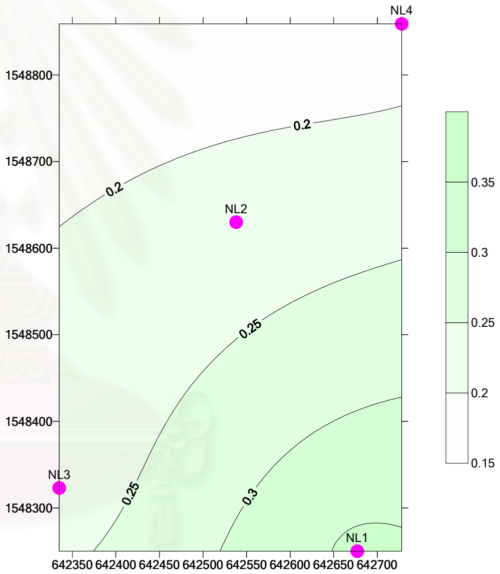
Lead (28 Oct. 01)



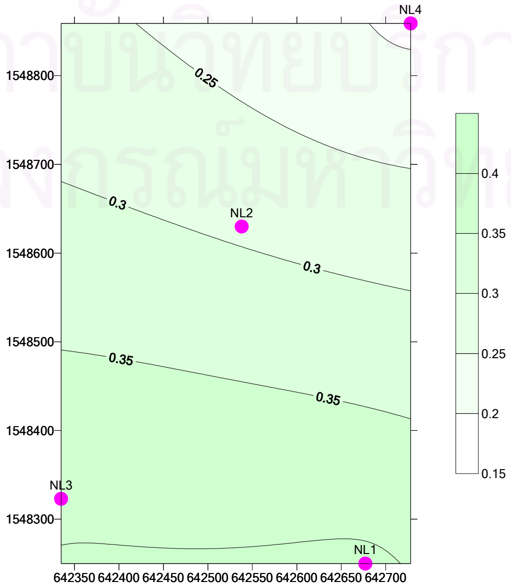
Lead (27 Jan. 02)



Lead (27 Mar. 02)



Lead (27 Jul. 02)



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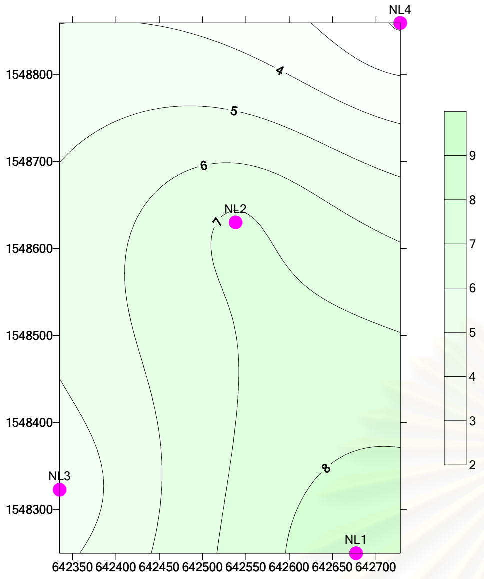
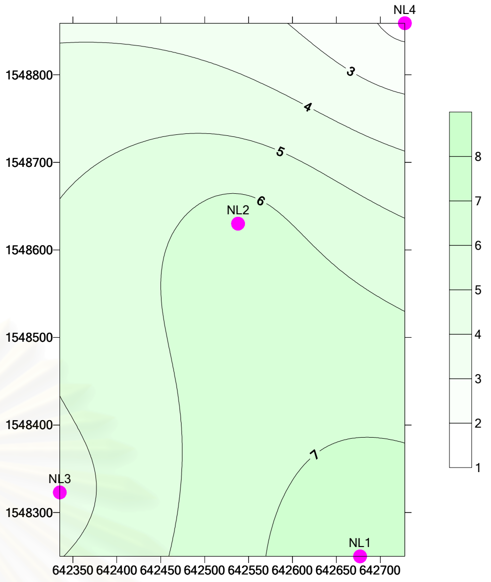
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

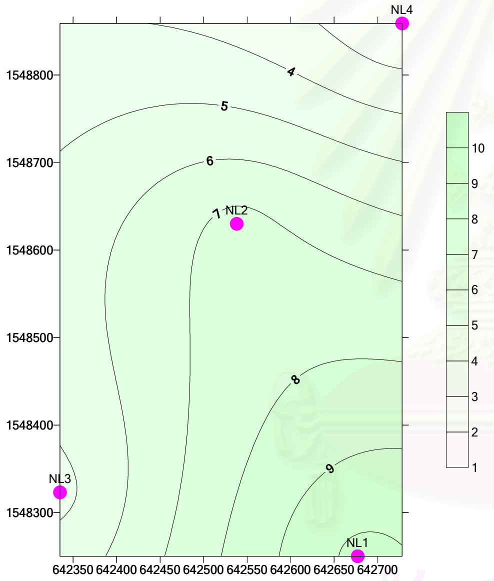
Manganese (18 Aug. 01)



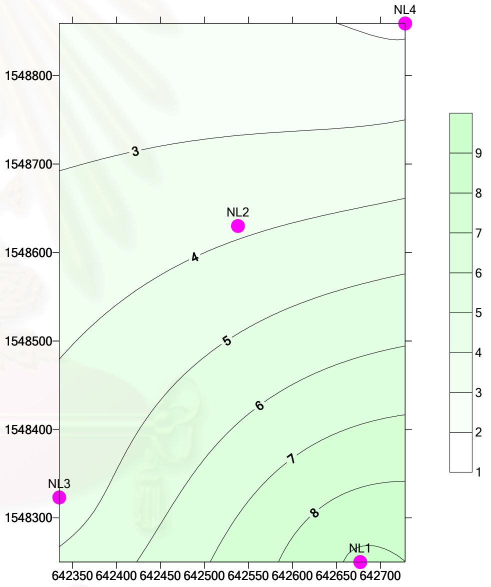
Manganese (28 Oct. 01)



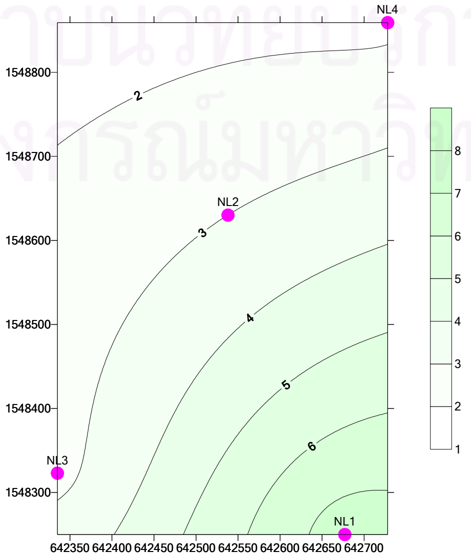
Manganese (27 Jan. 02)



Manganese (27 Mar. 02)



Manganese (27 Jul. 02)



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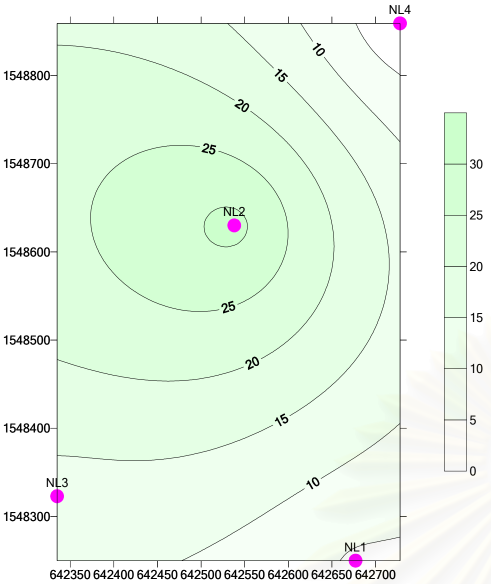
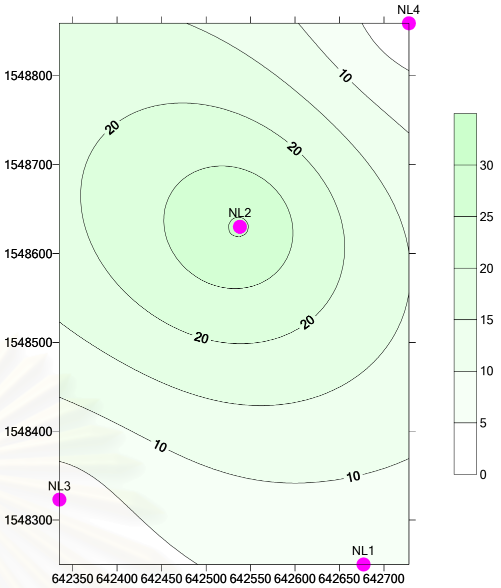
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

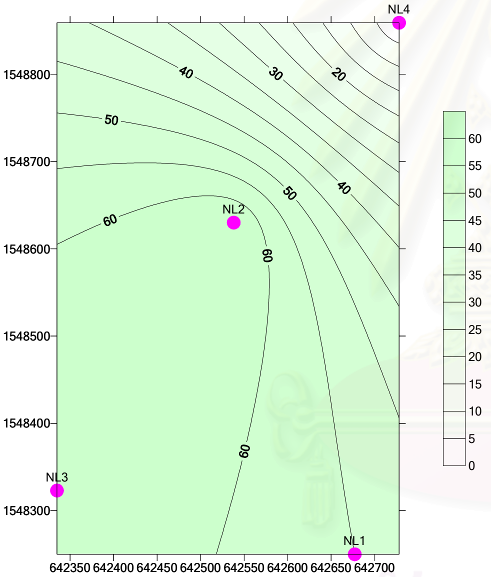
Total Iron (18 Aug. 01)



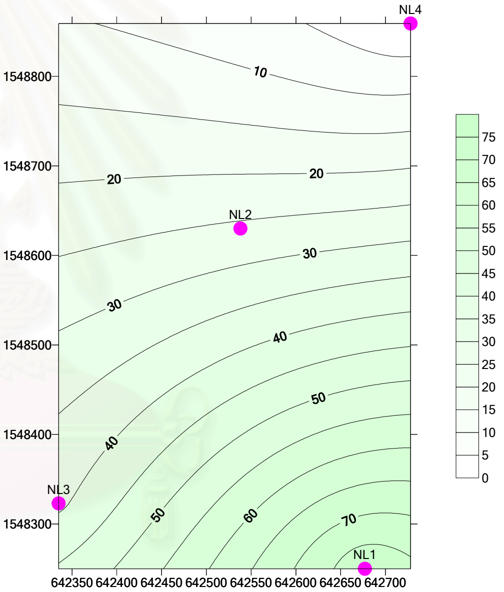
Total Iron (28 Oct. 01)



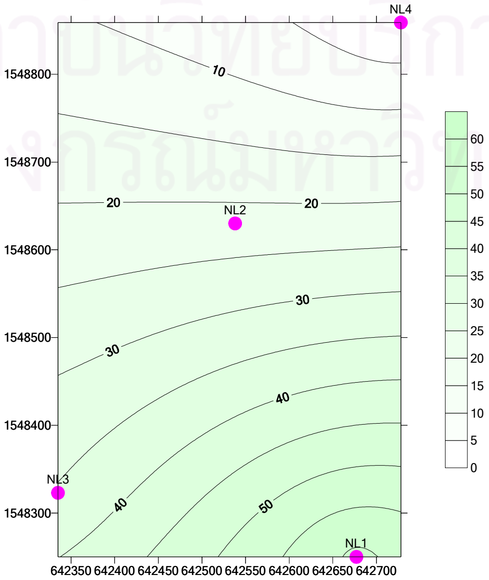
Total Iron (27 Jan. 02)



Total Iron (27 Mar. 02)



Total Iron (27 Jul. 02)



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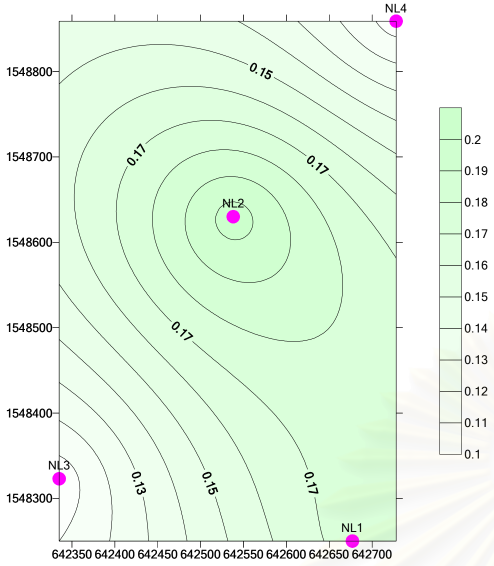
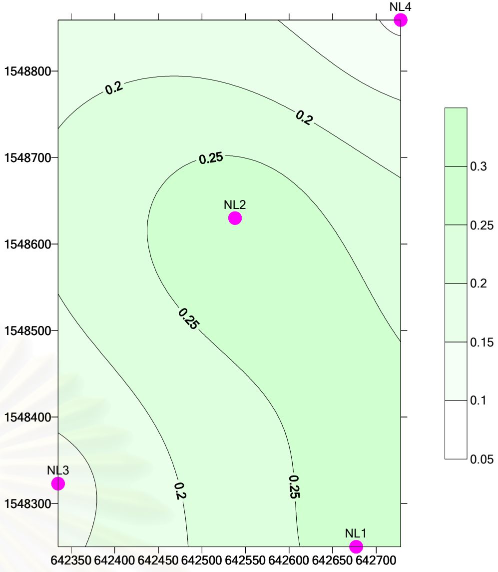
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

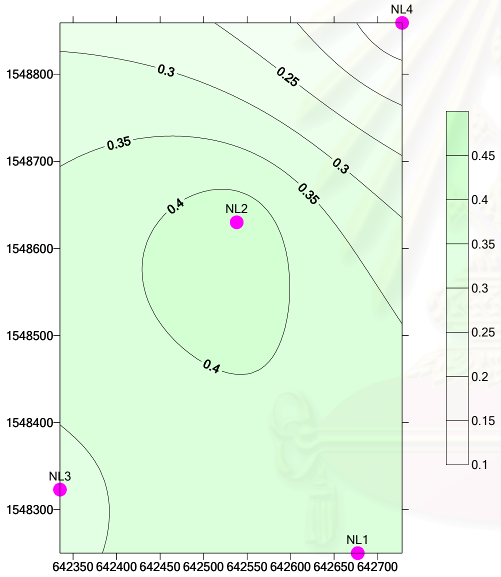
Nickel (18 Aug. 01)



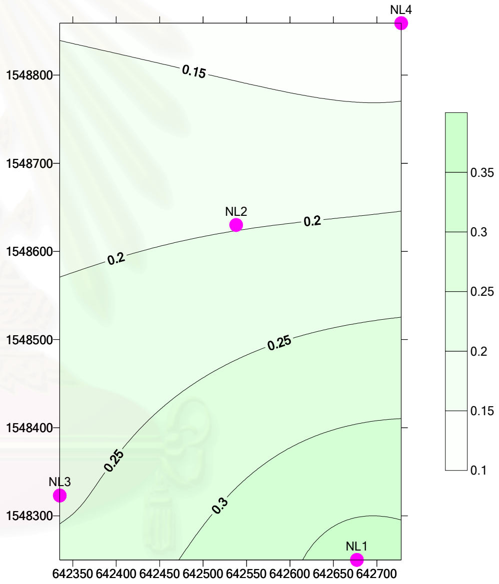
Nickel (28 Oct. 01)



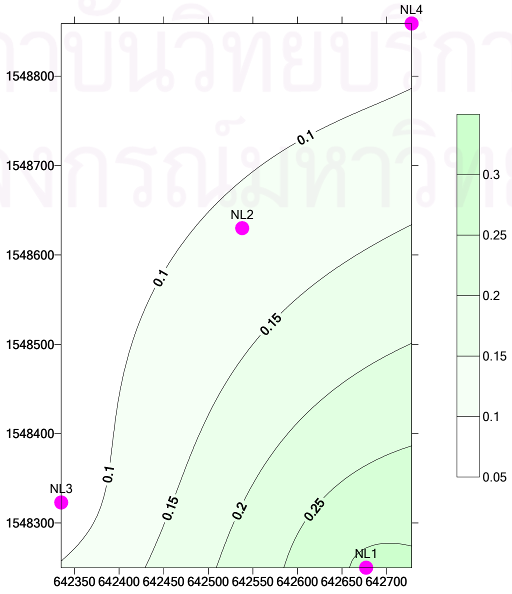
Nickel (27 Jan. 02)



Nickel (27 Mar. 02)



Nickel (27 Jul. 02)



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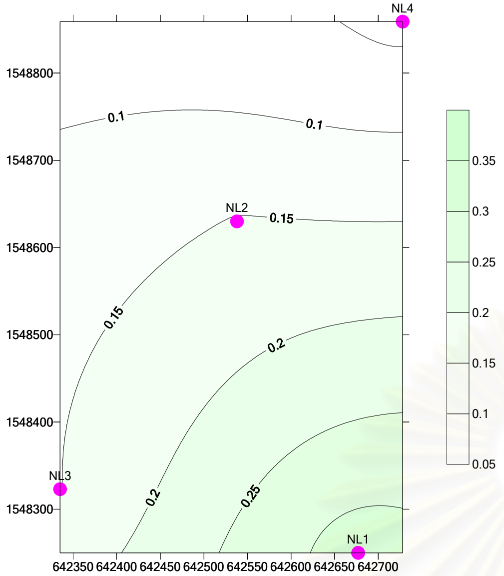
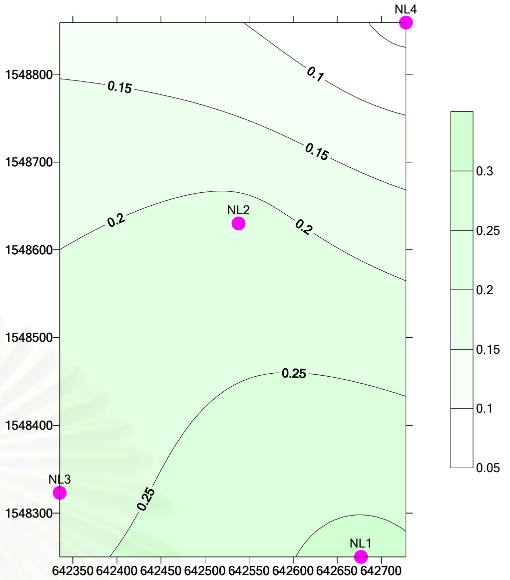
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

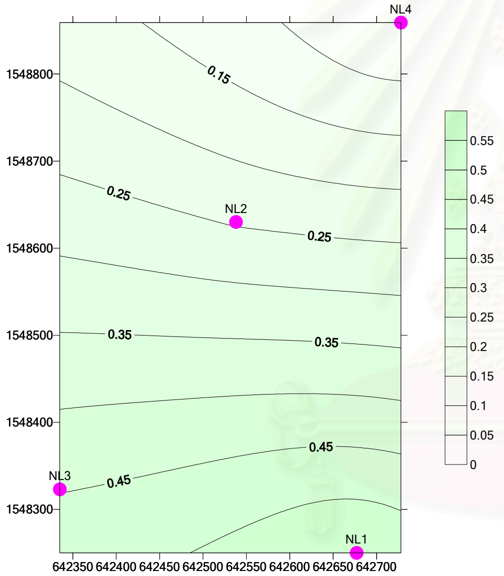
Zinc (18 Aug. 01)



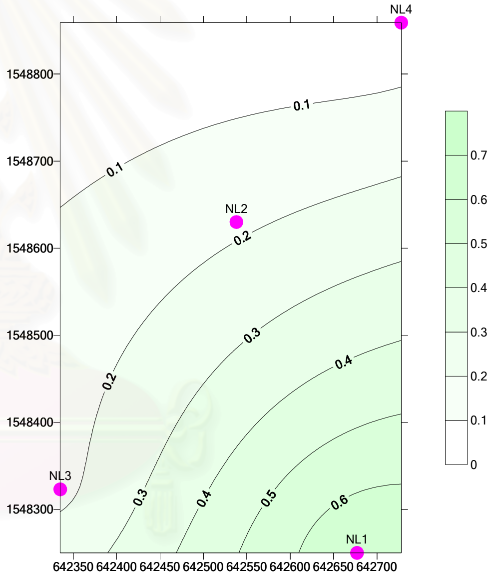
Zinc (28 Oct. 01)



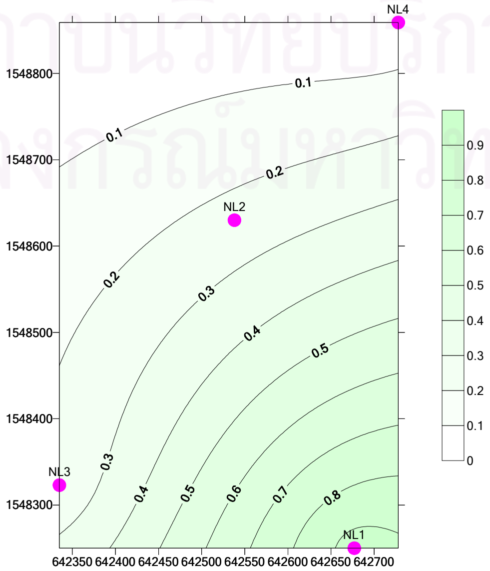
Zinc (27 Jan. 02)



Zinc (27 Mar. 02)



Zinc (27 Jul. 02)



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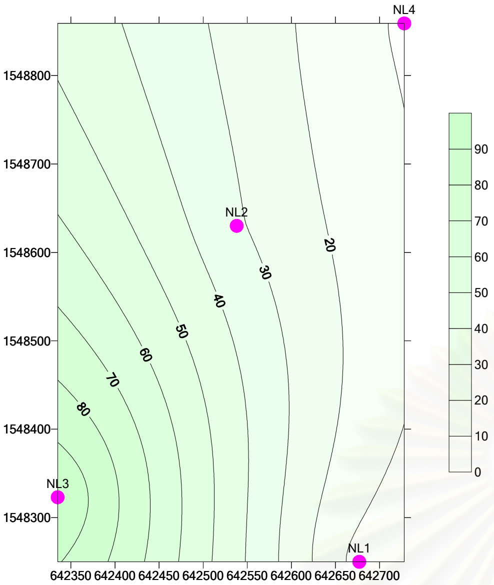
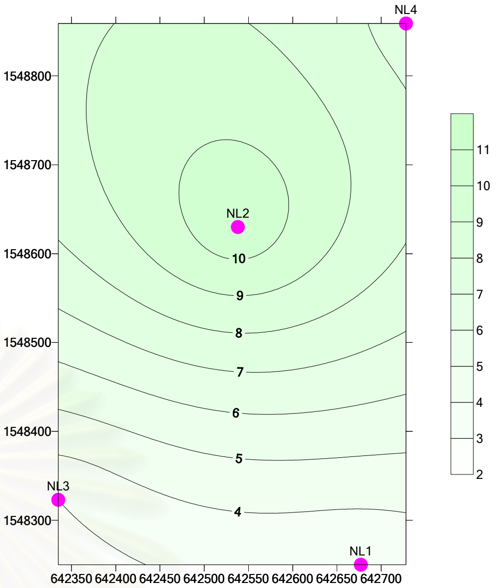
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

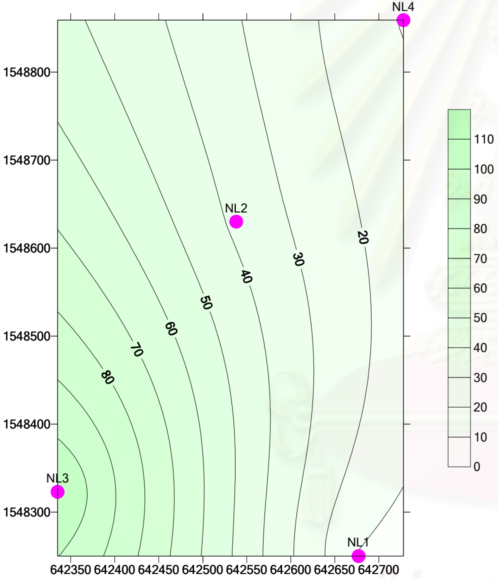
Arsenic (18 Aug. 01)



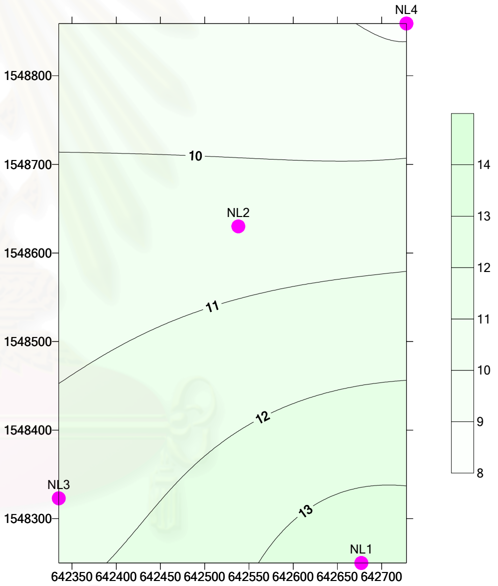
Arsenic (28 Oct. 01)



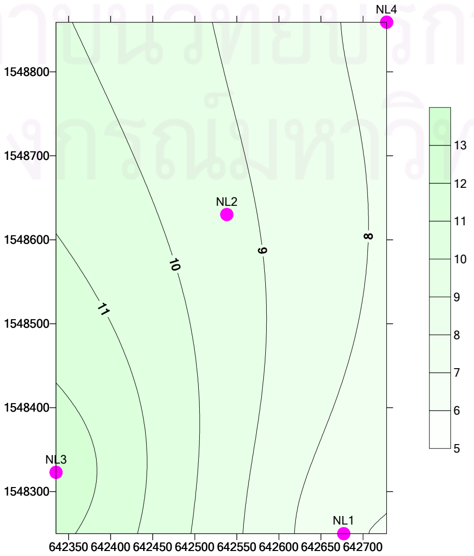
Arsenic (27 Jan. 02)



Arsenic (27 Mar. 02)



Arsenic (27 Jul. 02)



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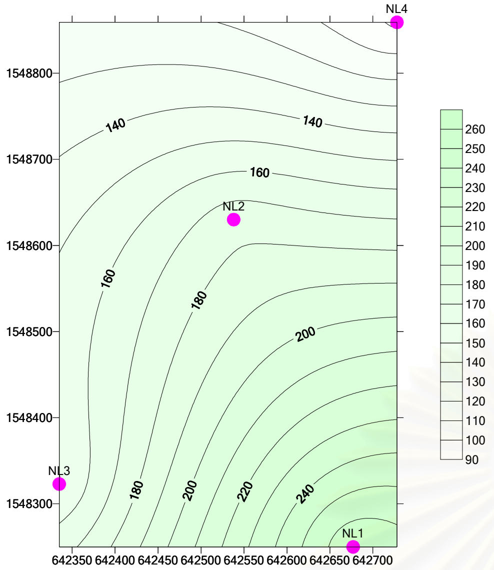
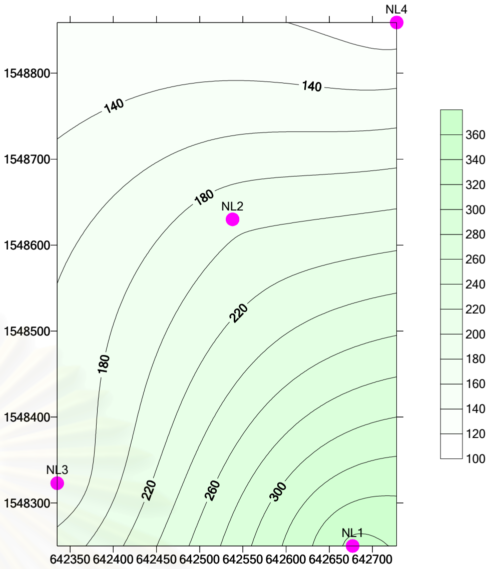
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

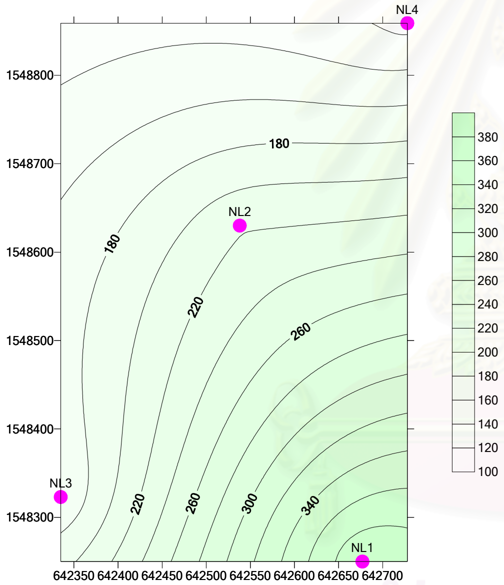
Magnesium (18 Aug. 01)



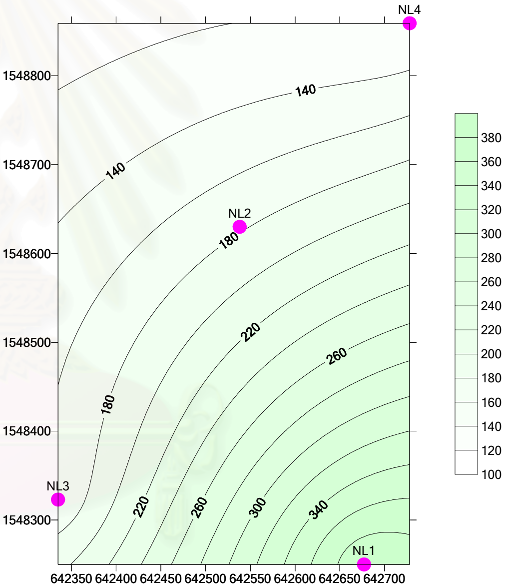
Magnesium (28 Oct. 01)



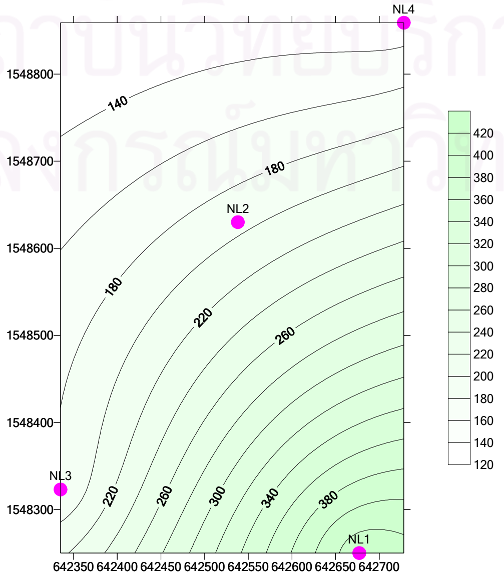
Magnesium (27 Jan. 02)



Magnesium (27 Mar. 02)



Magnesium (27 Jul. 02)



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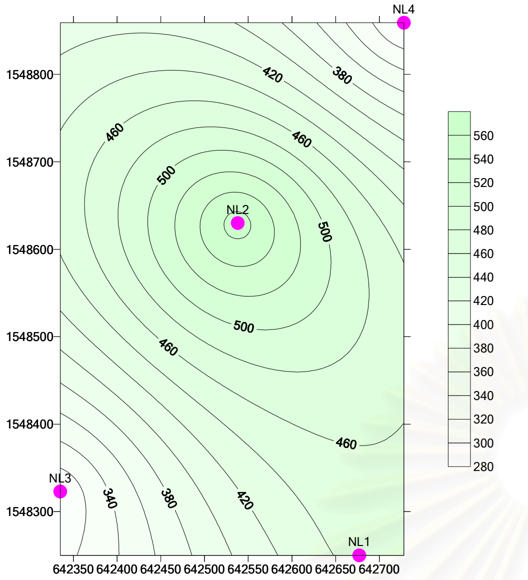
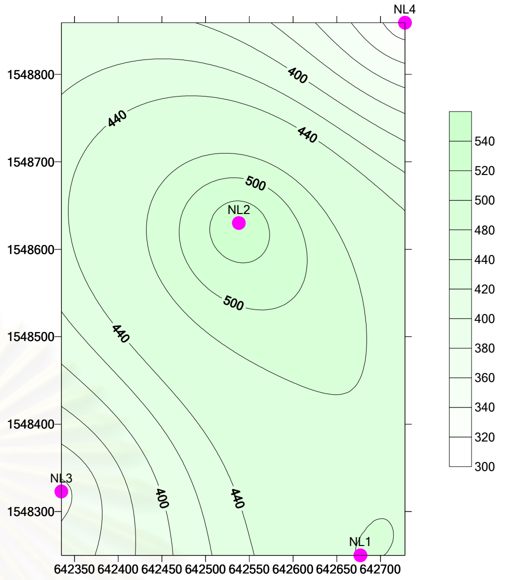
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

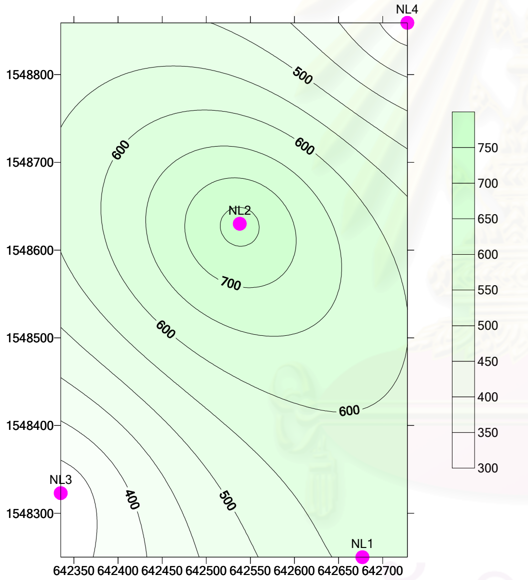
Calcium (18 Aug. 01)



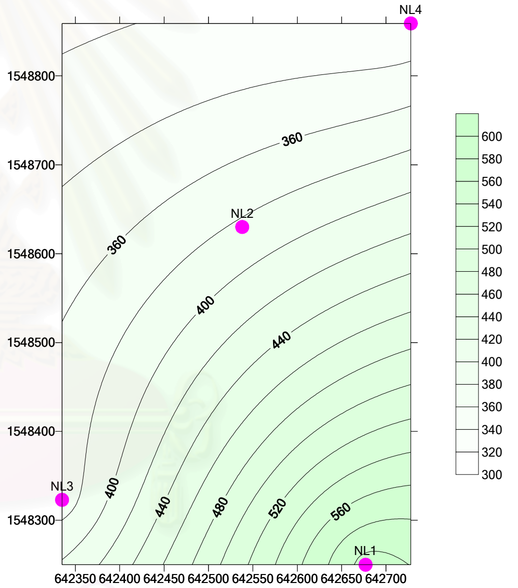
Calcium (28 Oct. 01)



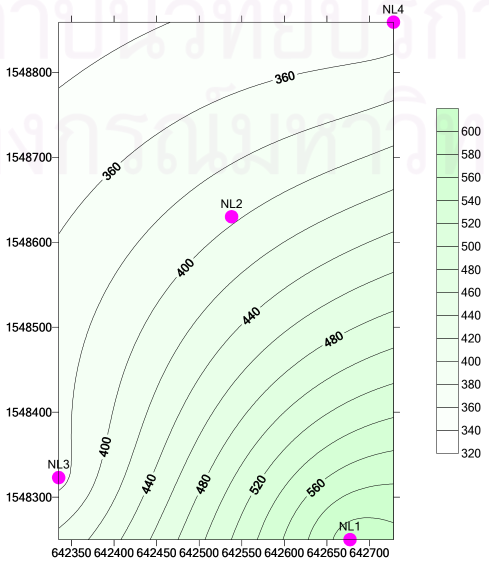
Calcium (27 Jan. 02)



Calcium (27 Mar. 02)



Calcium (27 Jul. 02)



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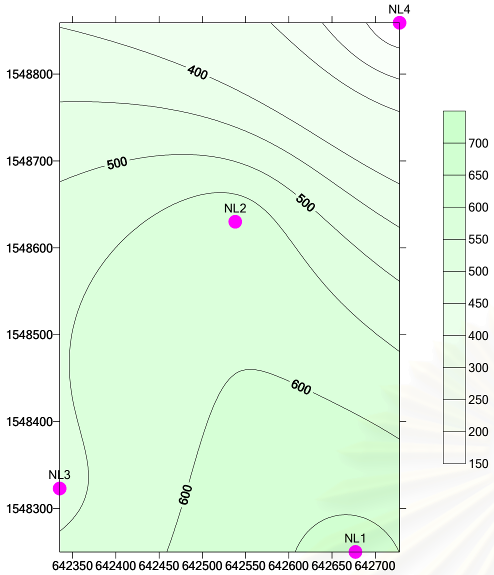
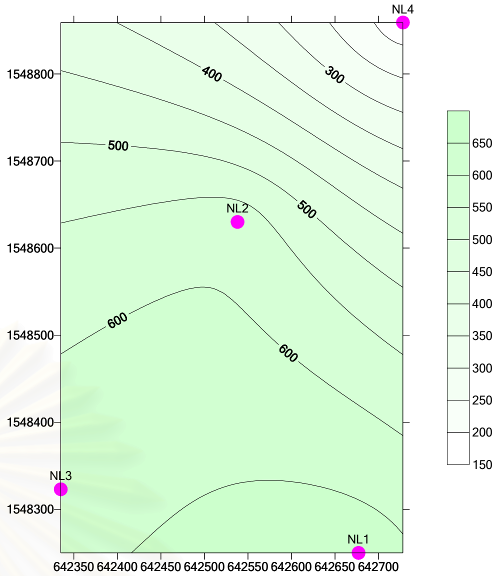
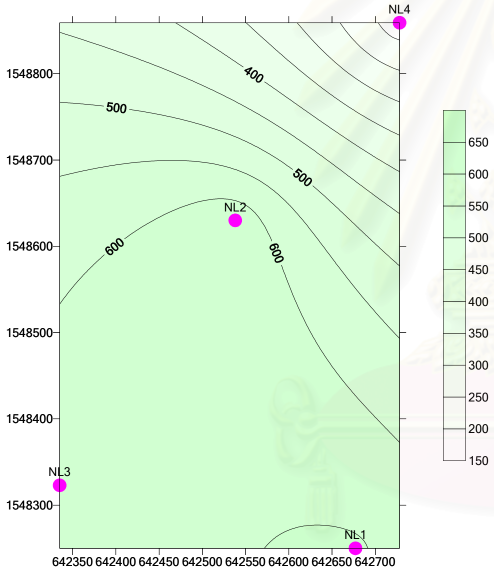
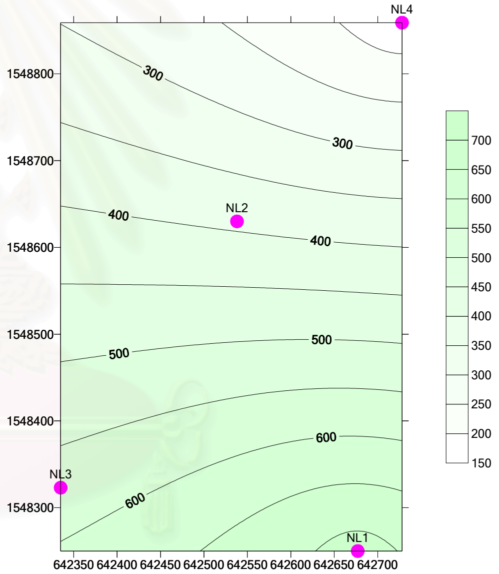
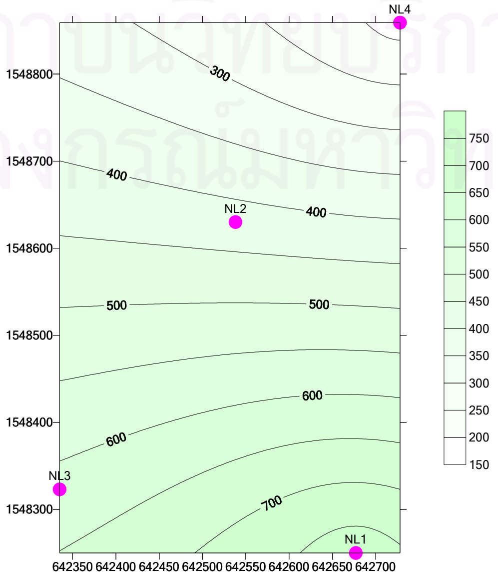
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)


Sodium (18 Aug. 01)


Sodium (28 Oct. 01)


Sodium (27 Jan. 02)


Sodium (27 Mar. 02)


Sodium (27 Jul. 02)

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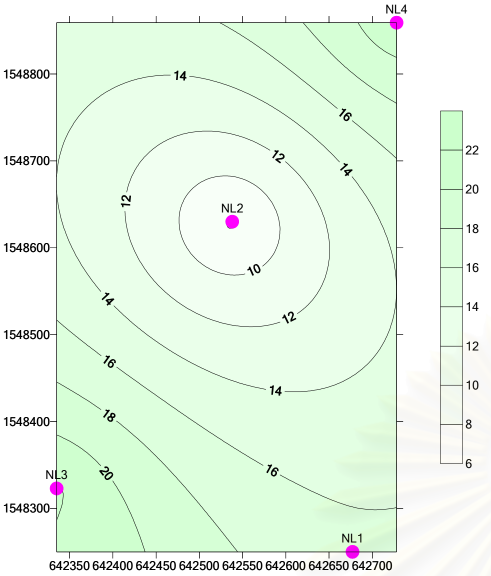
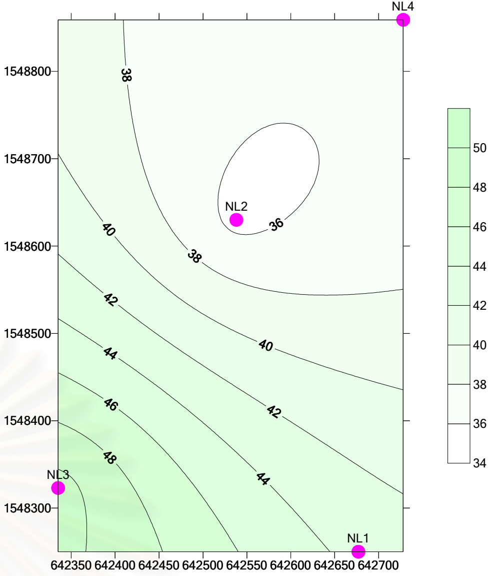
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

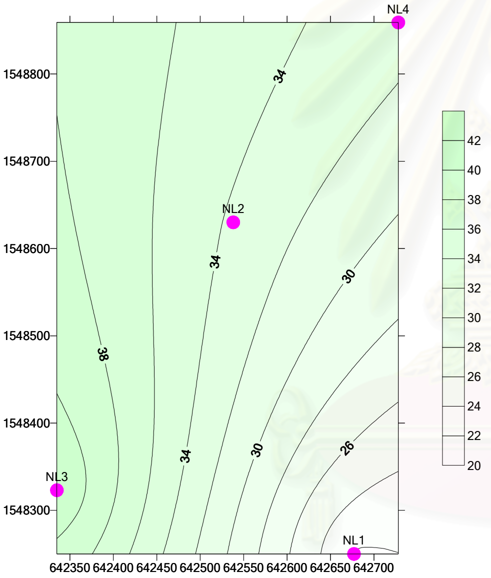
Potassium (18 Aug. 01)



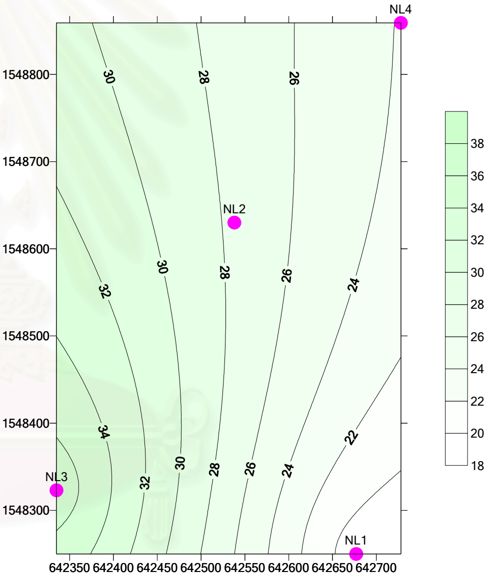
Potassium (28 Oct. 01)



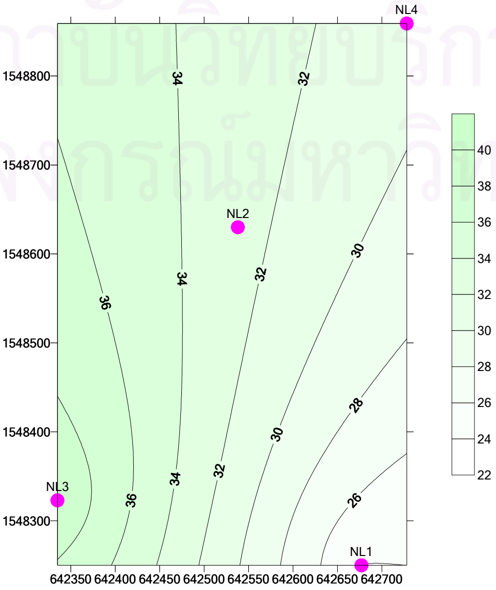
Potassium (27 Jan. 02)



Potassium (27 Mar. 02)



Potassium (27 Jul. 02)



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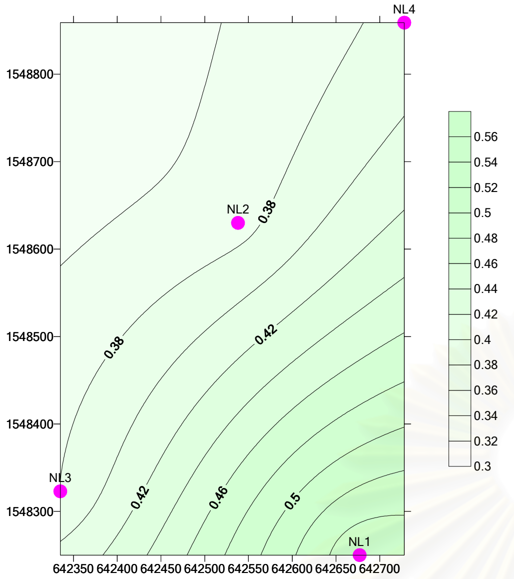
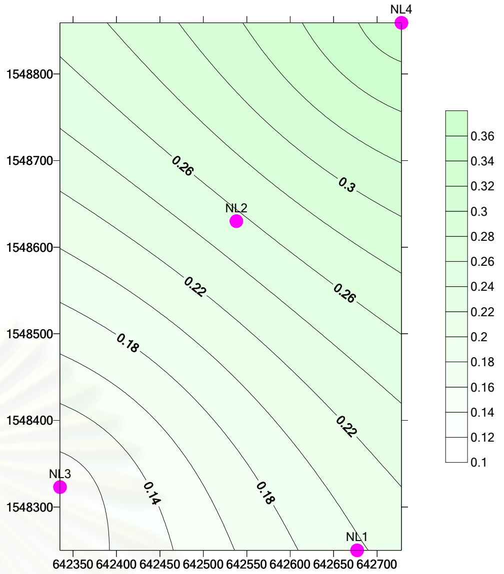
Appendix III.1 Contour line of chemical analysis: shallow subsurface water (cont.)

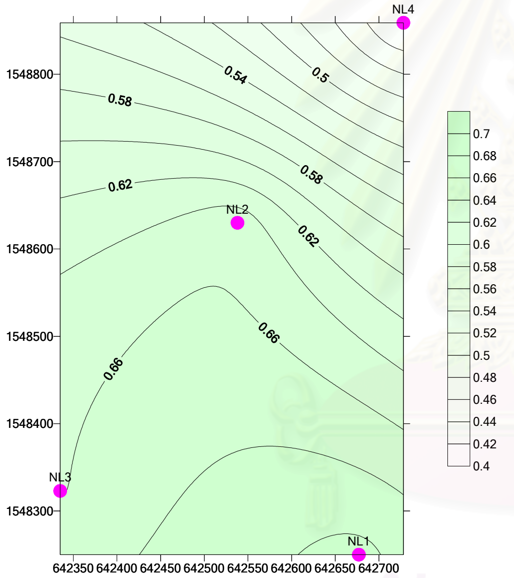
Copper (18 Aug. 01)



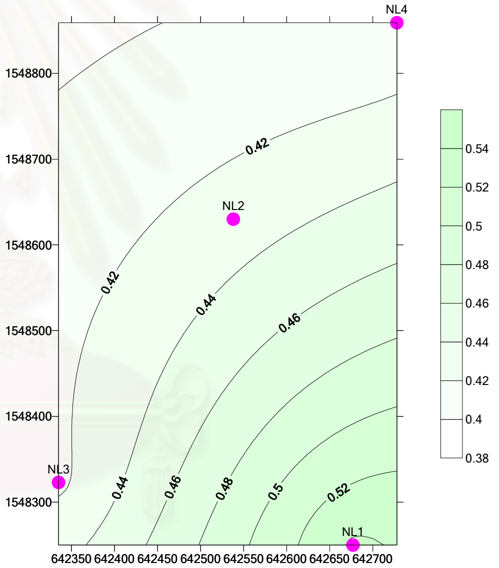
Copper (28 Oct. 01)



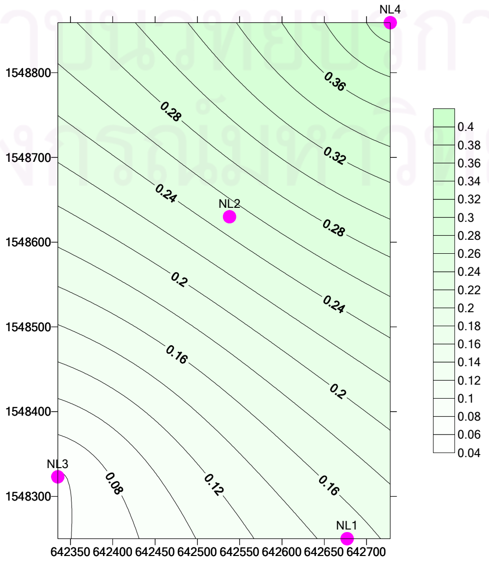
Copper (27 Jan. 02)



Copper (27 Mar. 02)



Copper (27 Jul. 02)



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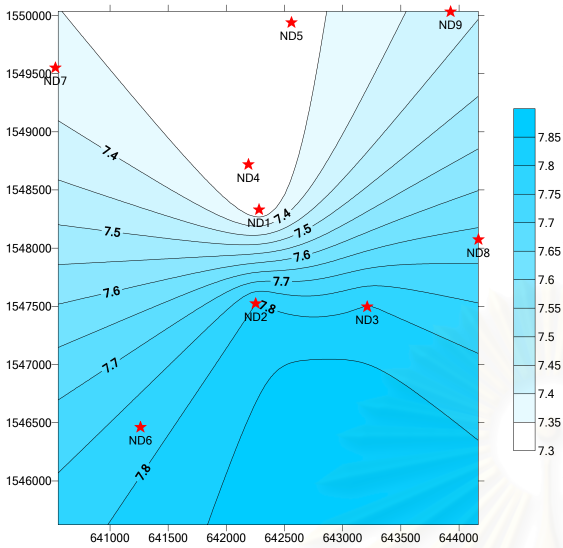
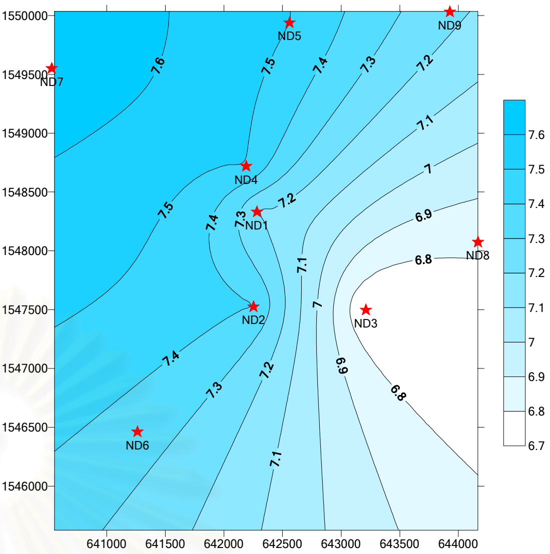
Appendix III.2 Contour line of chemical analysis: deep well water

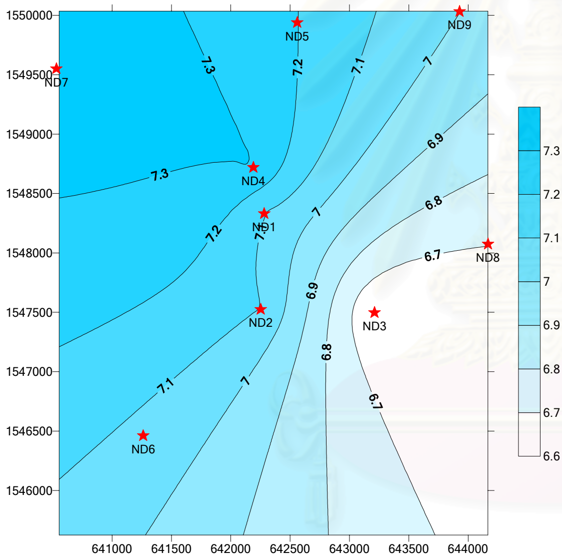
pH (18 Aug. 01)



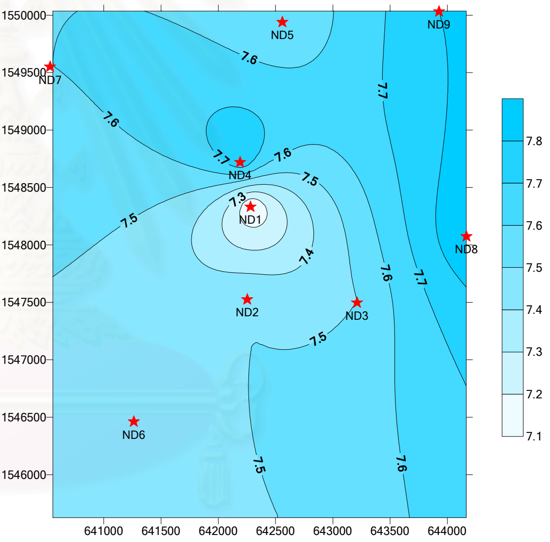
pH (28 Oct. 01)



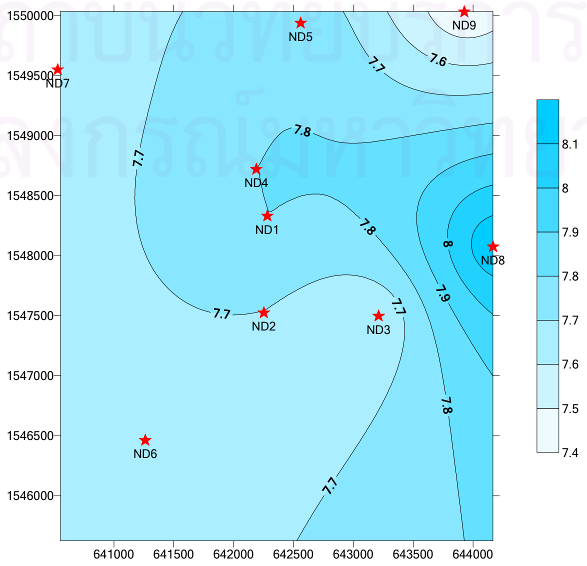
pH (27 Jan. 02)



pH (27 Mar. 02)



pH (27 Jul. 02)



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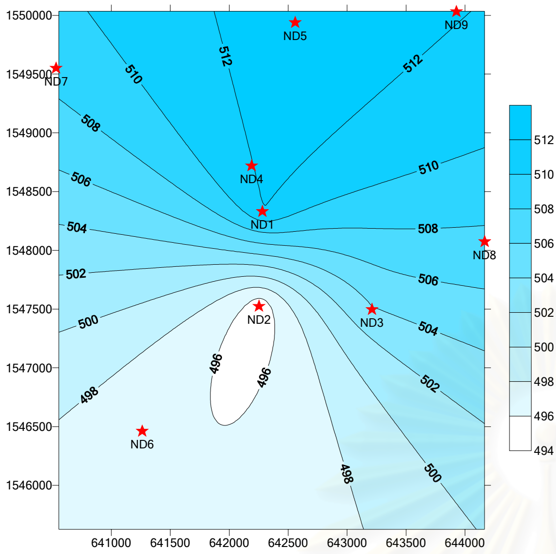
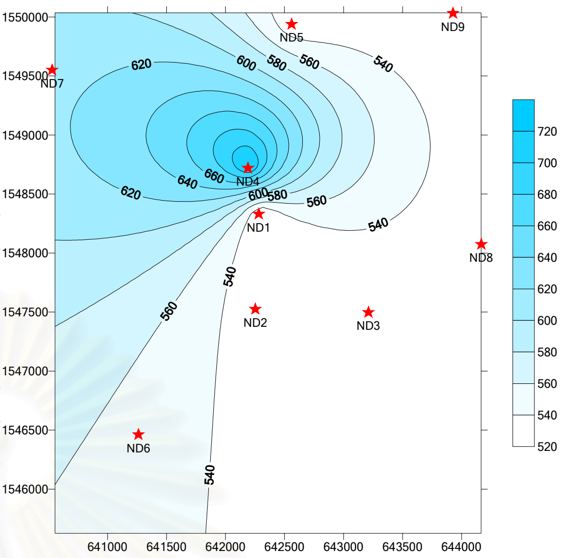
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

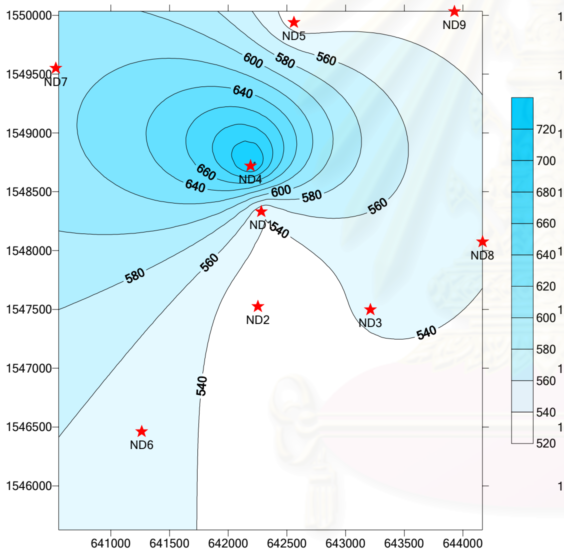
Electrical Conductivity (18 Aug. 01)



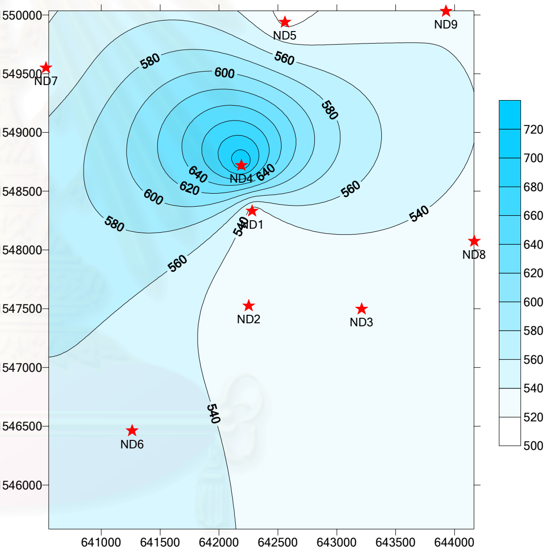
Electrical Conductivity (28 Oct. 01)



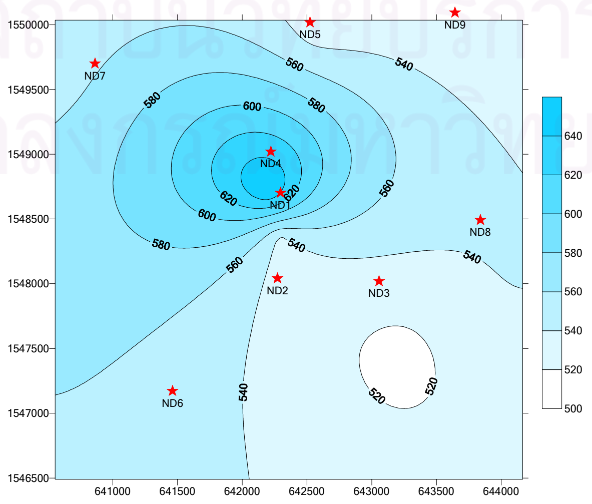
Electrical Conductivity (27 Jan. 02)



Electrical Conductivity (27 Mar. 02)



Electrical Conductivity (27 Jul. 02)



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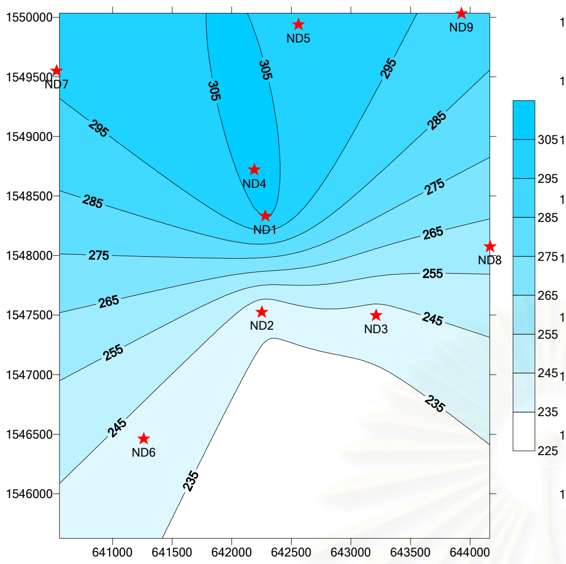
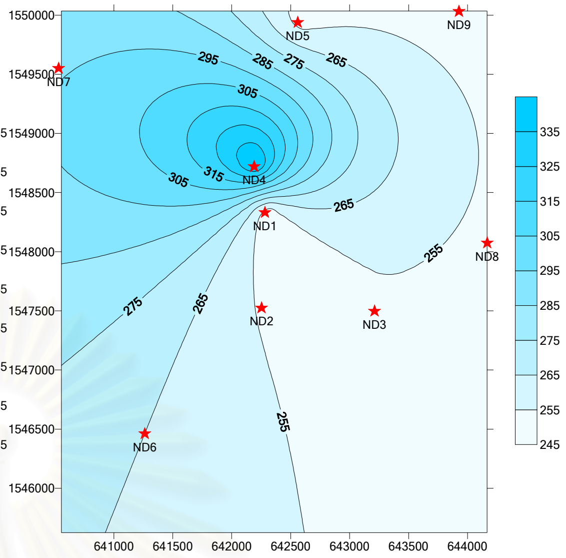
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

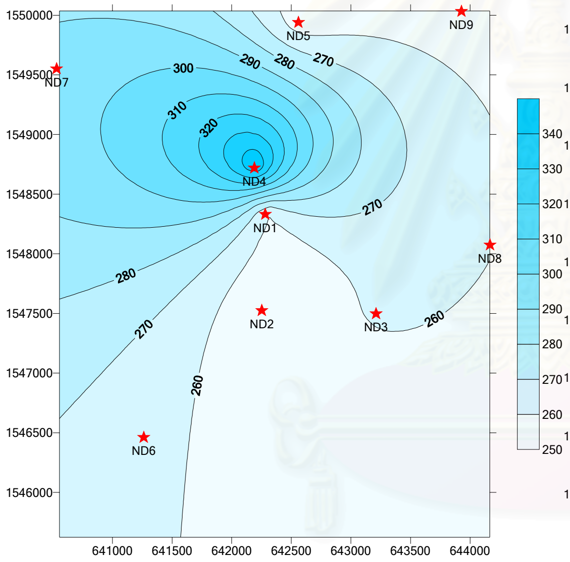
Total Dissolved Solid (18 Aug. 01)



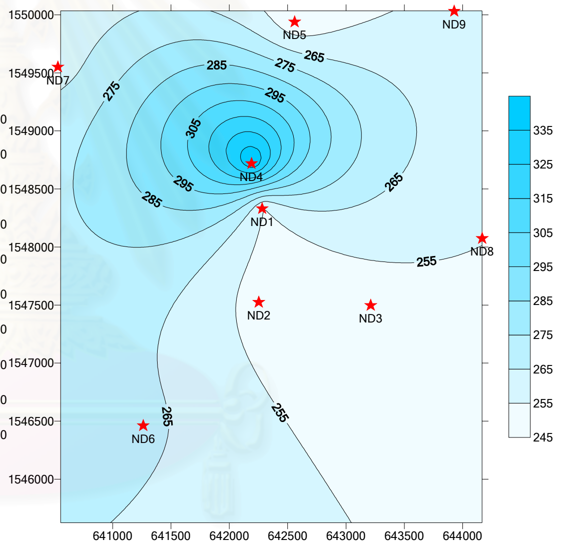
Total Dissolved Solid (28 Oct. 01)



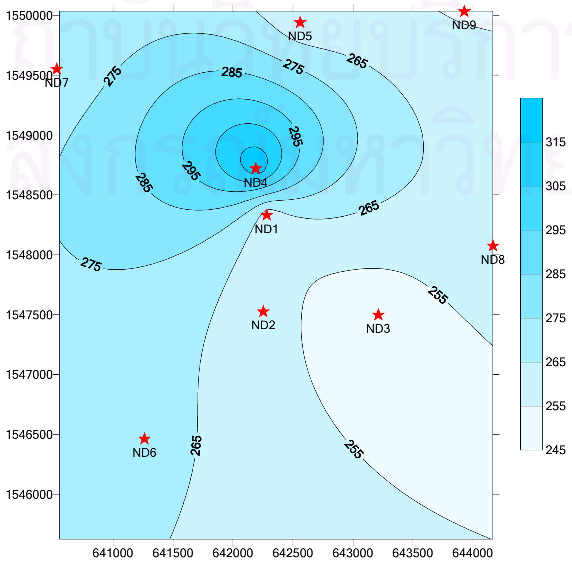
Total Dissolved Solid (27 Jan. 02)



Total Dissolved Solid (27 Mar. 02)



Total Dissolved Solid (27 Jul. 02)



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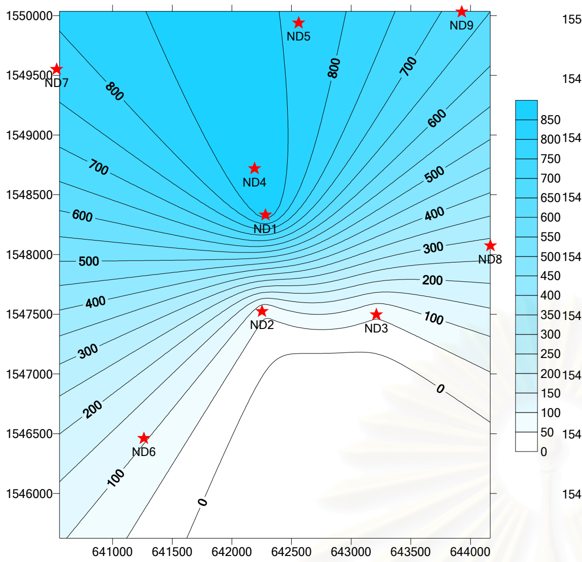
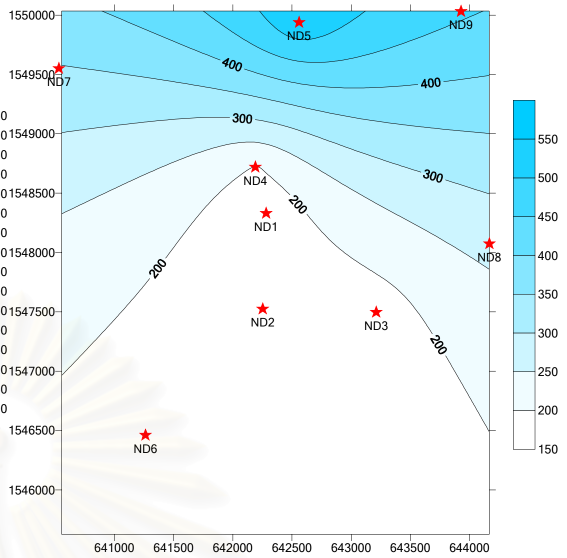
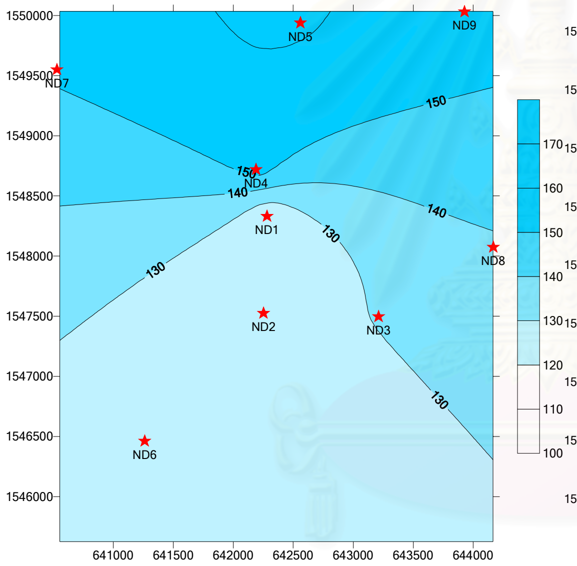
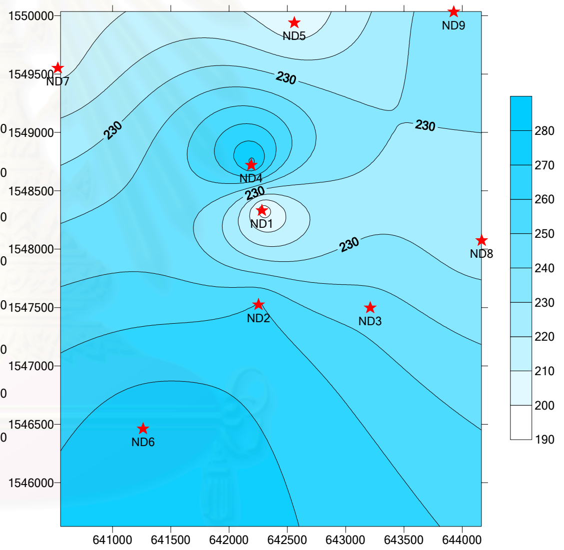
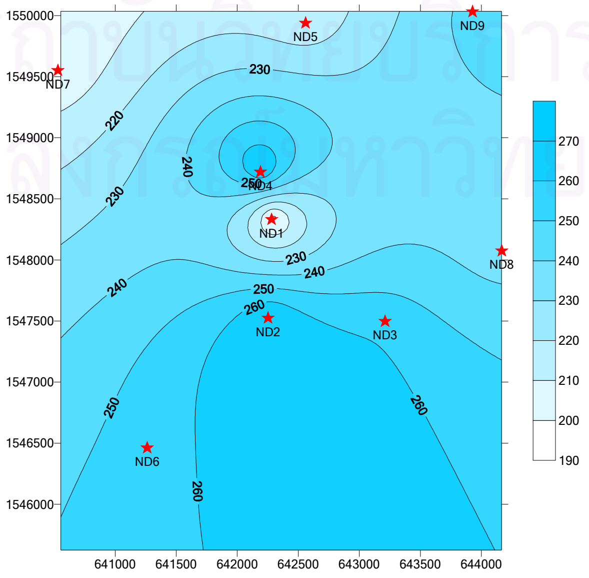
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)


Total Hardness (18 Aug. 01)


Total Hardness (28 Oct. 01)


Total Hardness (27 Jan. 02)


Total Hardness (27 Mar. 02)


Total Hardness (27 Jul. 02)

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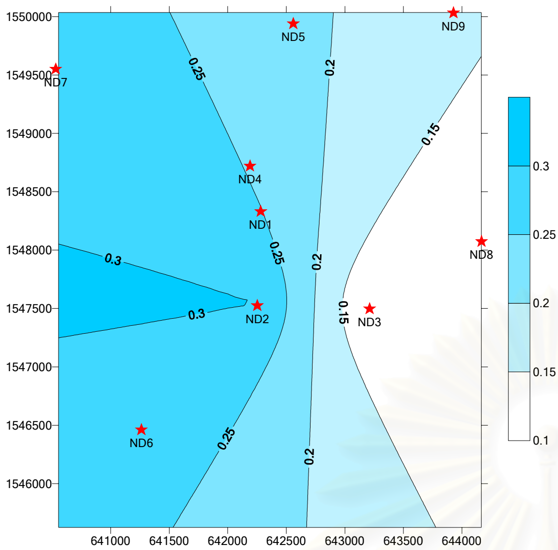
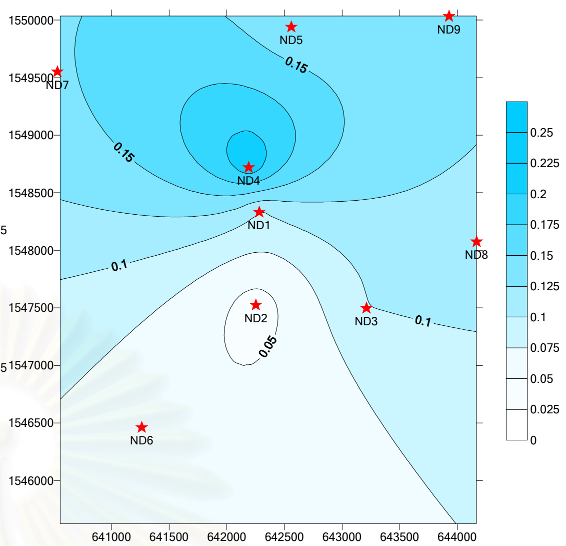
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

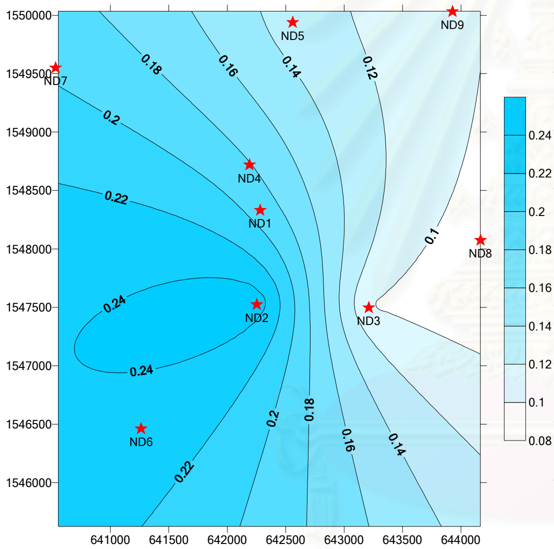
Lead (18 Aug. 01)



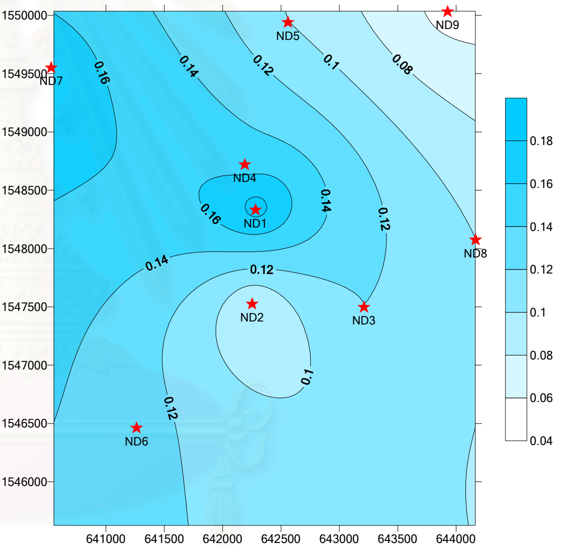
Lead (28 Oct. 01)



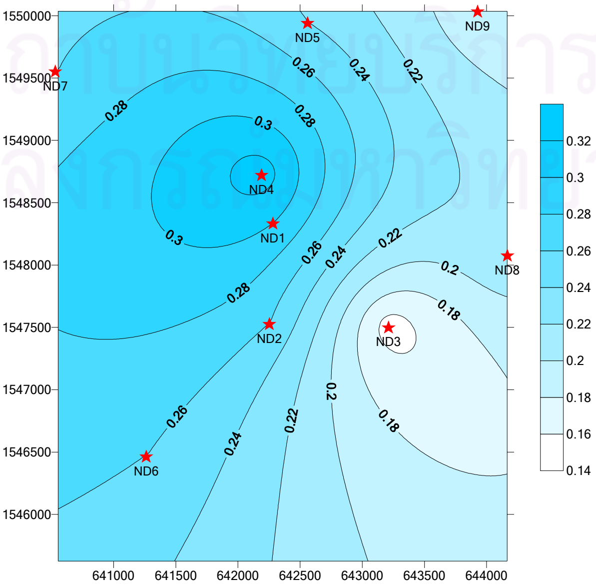
Lead (27 Jan. 02)



Lead (27 Mar. 02)



Lead (27 Jul. 02)



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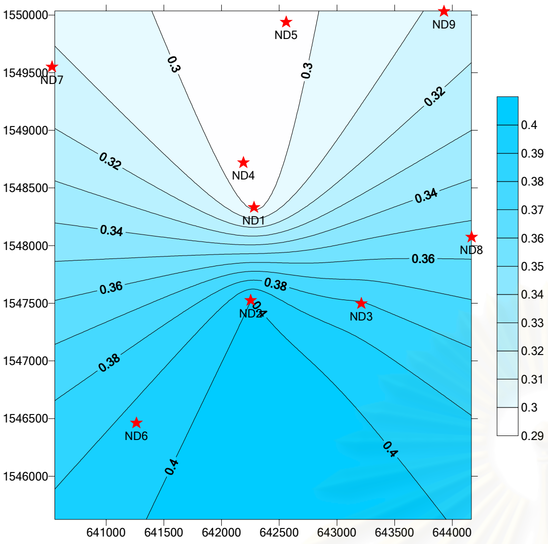
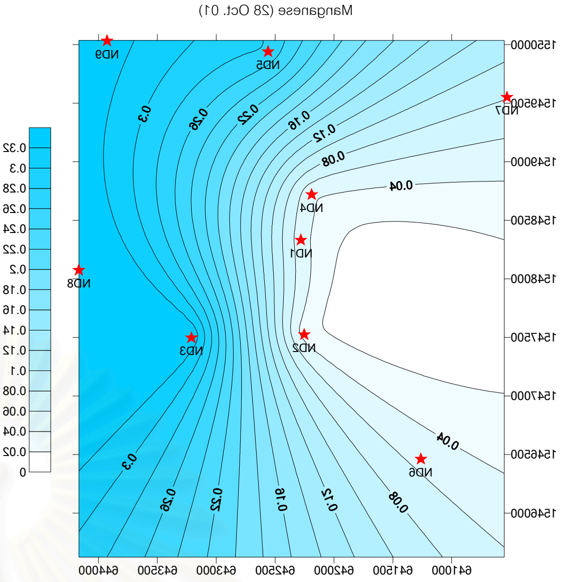
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

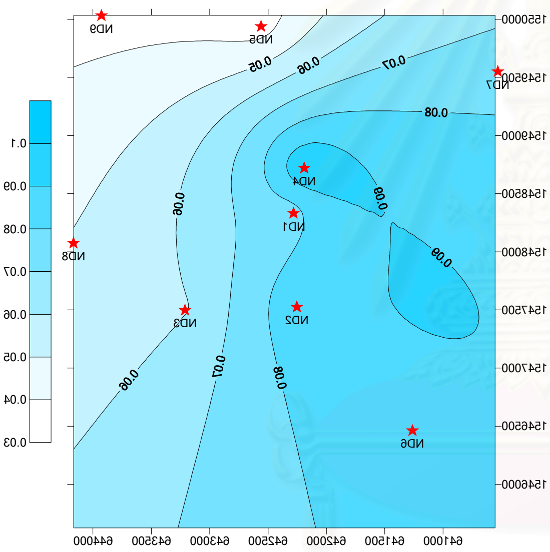
Manganese (18 Aug. 01)



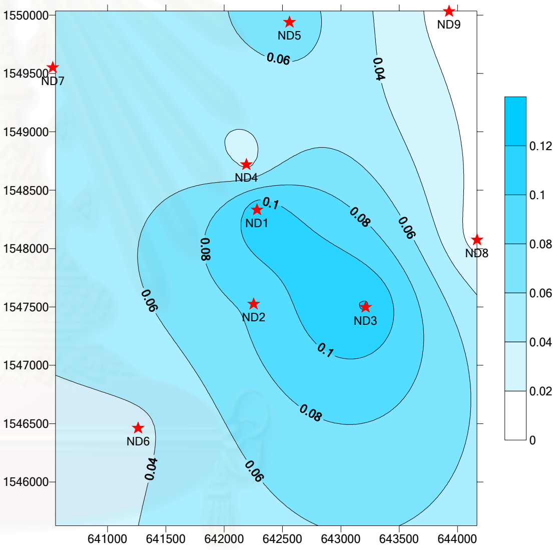
Manganese (28 Oct. 01)



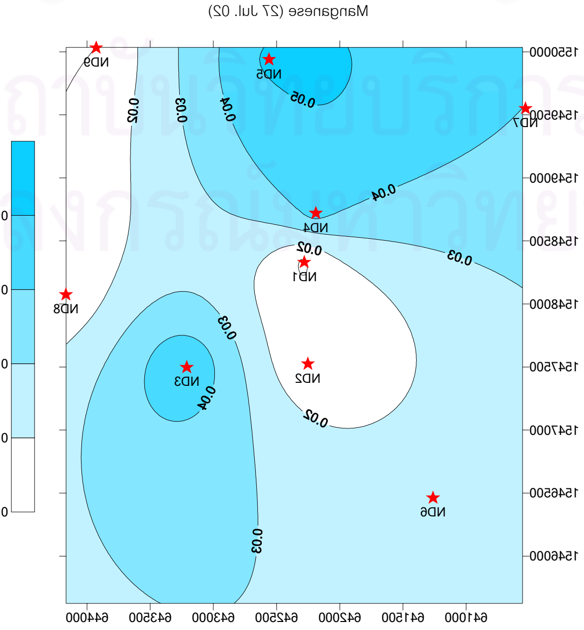
Manganese (27 Jan. 02)



Manganese (27 Mar. 02)

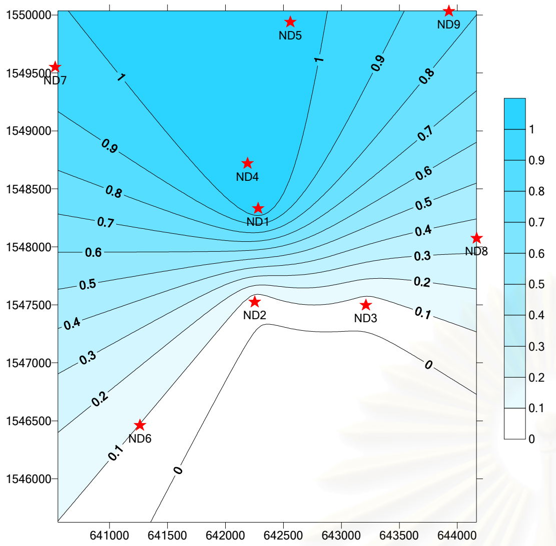


Manganese (27 Jul. 02)

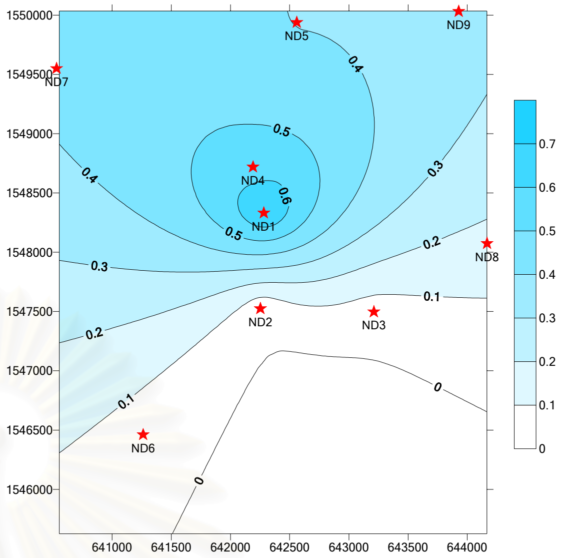


Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

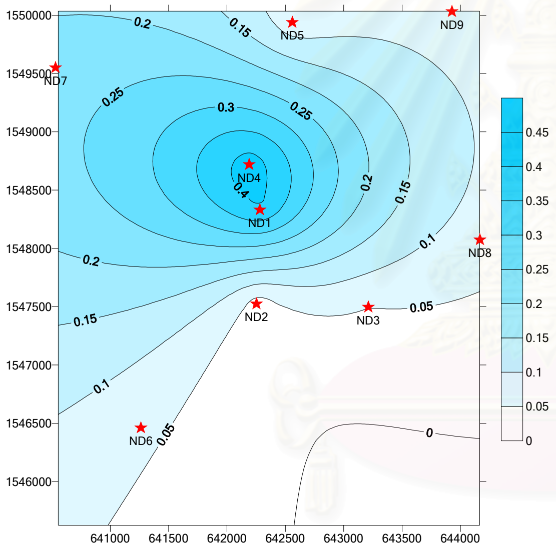
Zinc (18 Aug. 01)



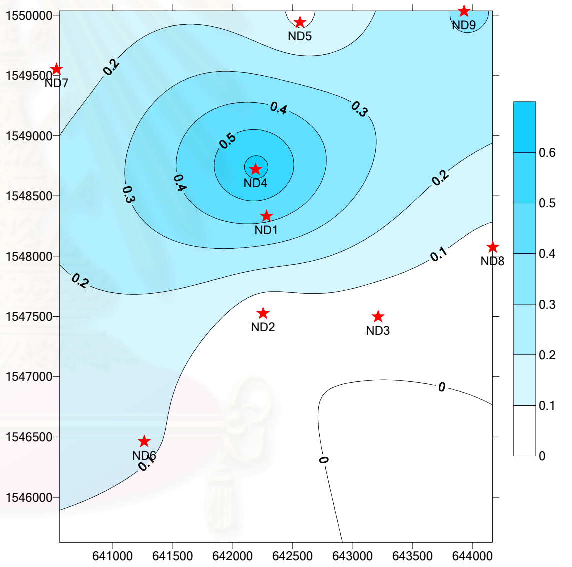
Zinc (28 Oct. 01)



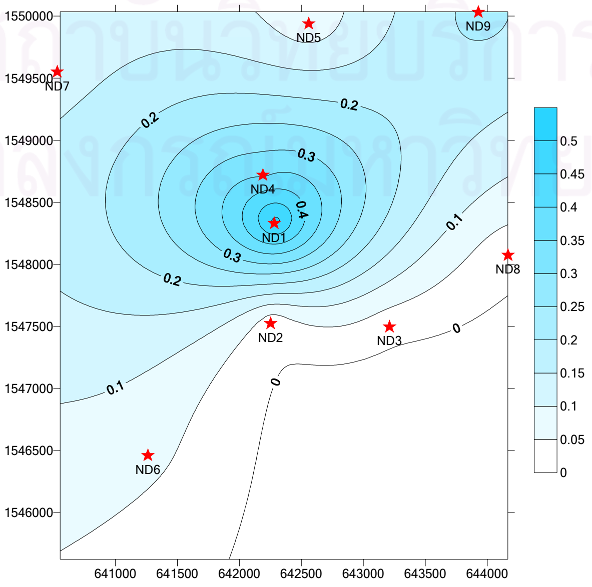
Zinc (27 Jan. 02)



Zinc (27 Mar. 02)



Zinc (27 Jul. 02)



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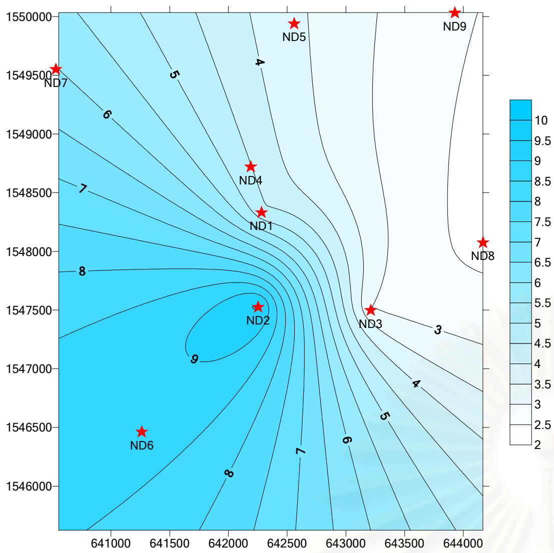
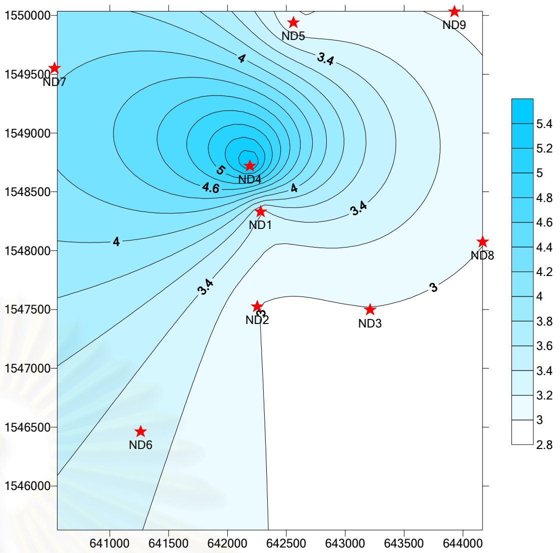
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

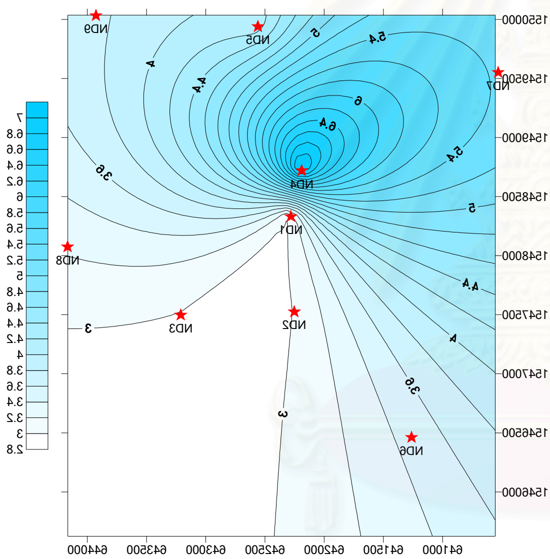
Arsenic (18 Aug. 01)



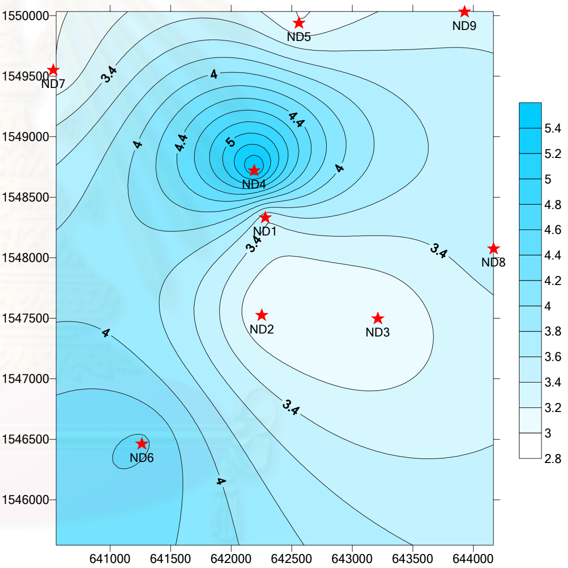
Arsenic (28 Oct. 01)



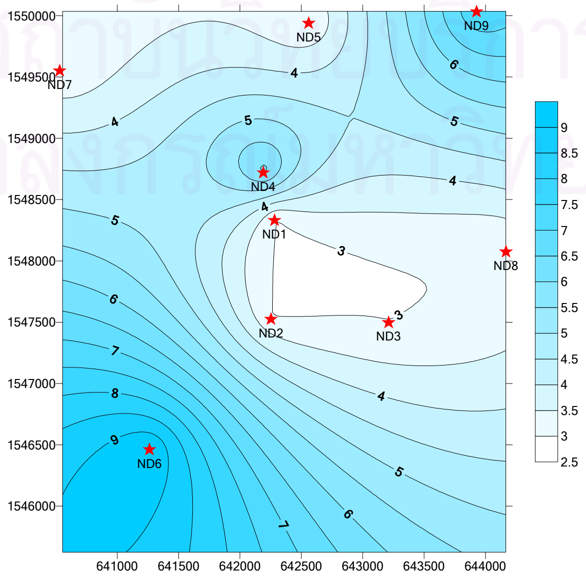
Arsenic (27 Jan. 02)



Arsenic (27 Mar. 02)

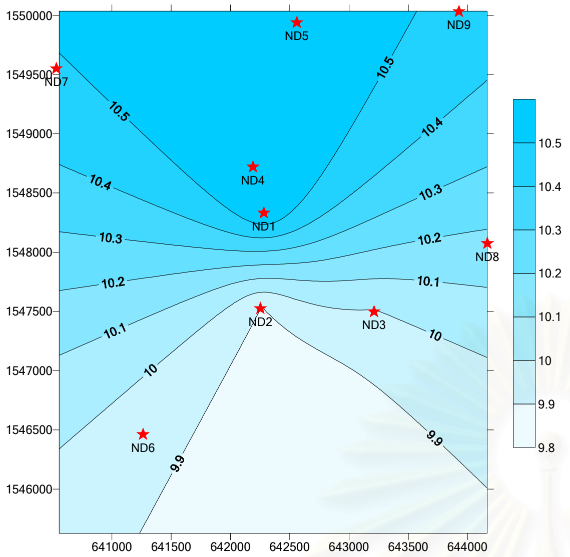


Arsenic (27 Jul. 02)

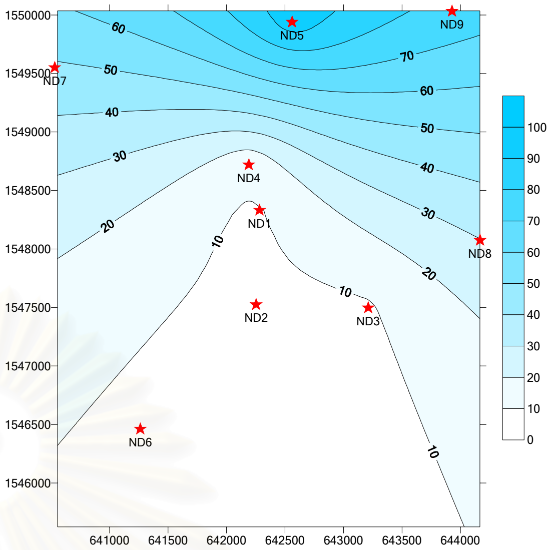


Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

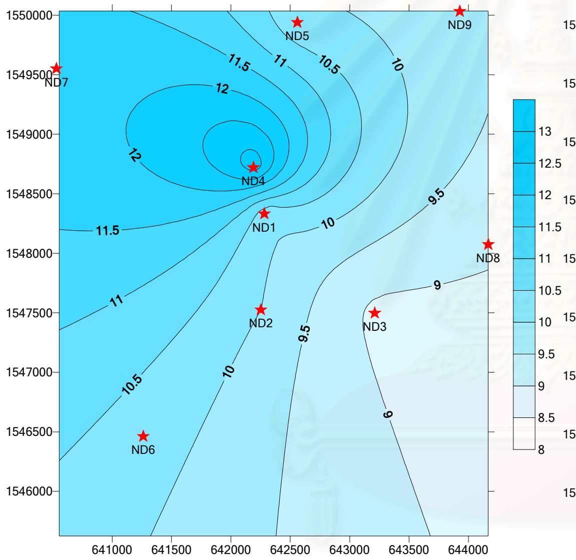
Magnesium (18 Aug. 01)



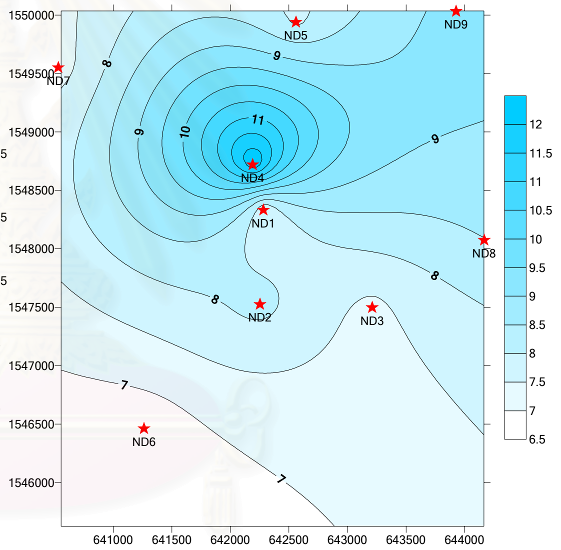
Magnesium (18 Oct. 01)



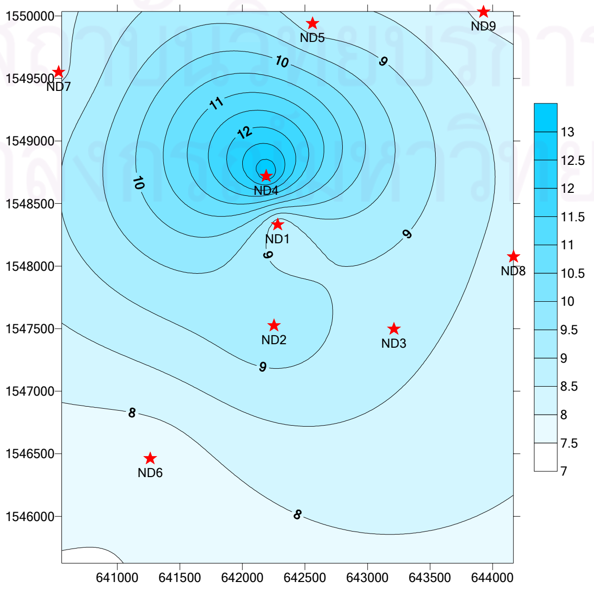
Magnesium (27 Jan. 02)



Magnesium (27 Mar. 02)



Magnesium (27 Jul. 02)



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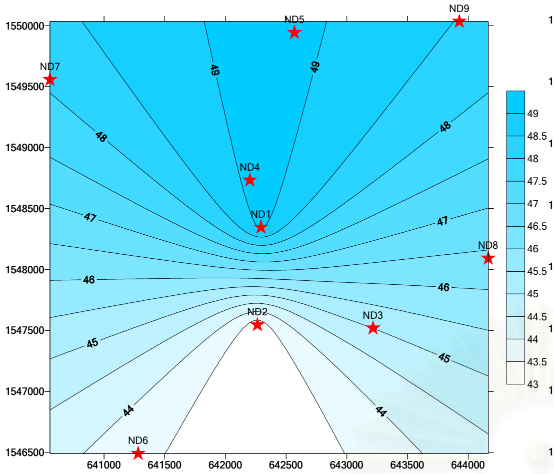
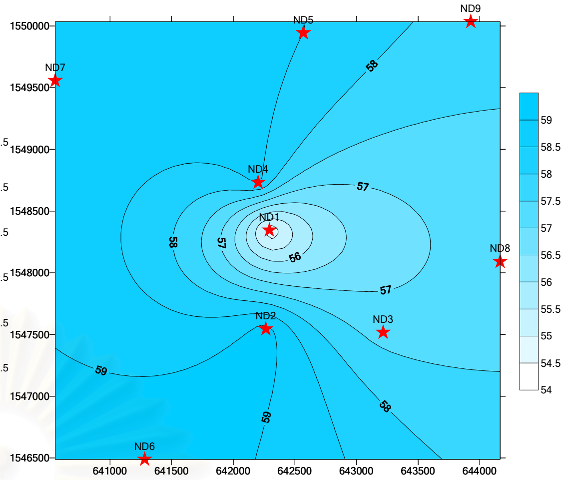
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

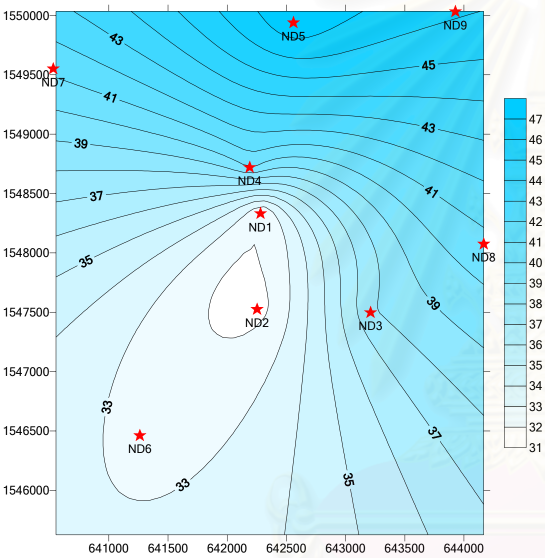
Calcium (18 Aug. 01)



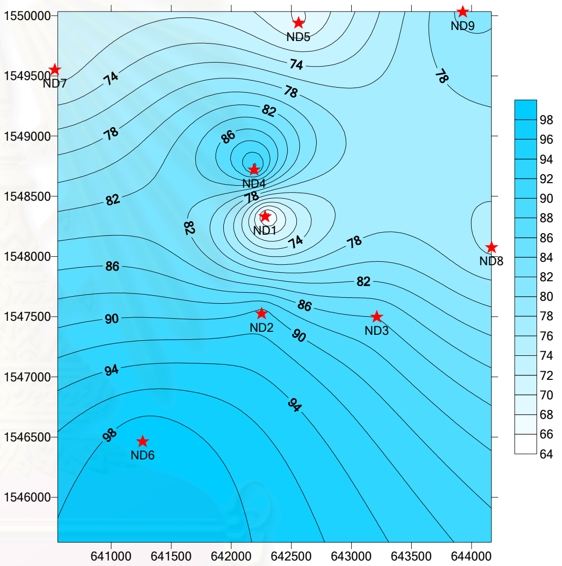
Calcium (28 Oct. 01)



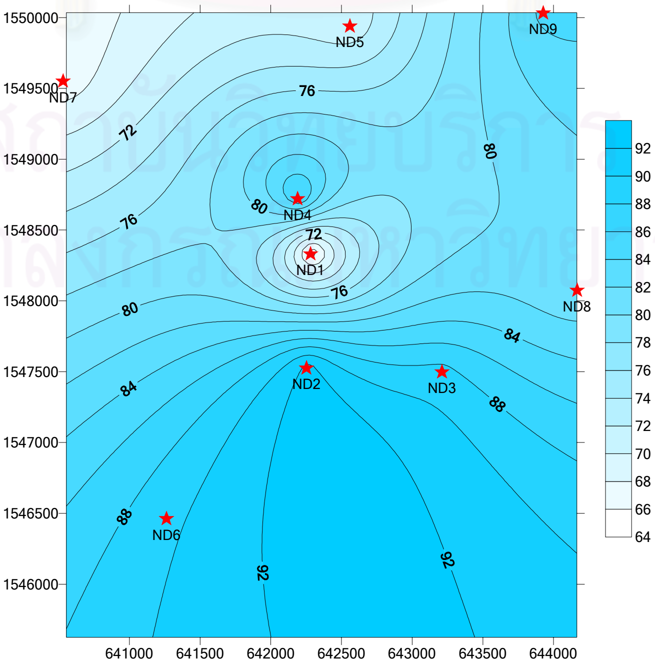
Calcium (27 Jan. 02)



Calcium (27 Mar. 02)



Calcium (27 Jul. 02)



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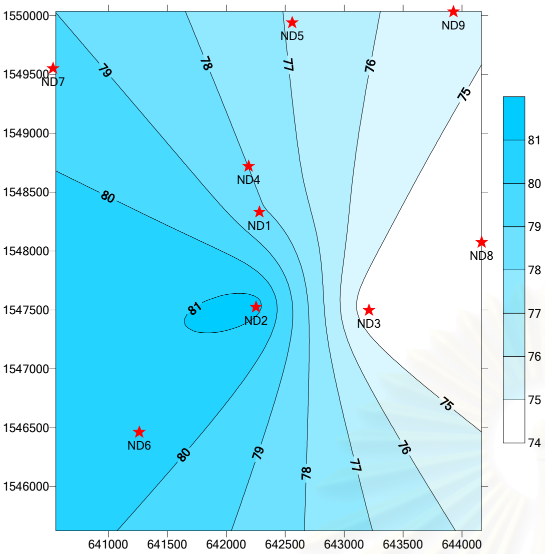
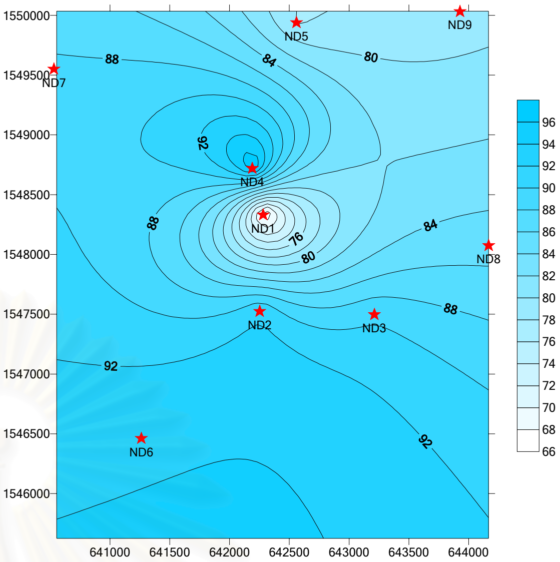
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

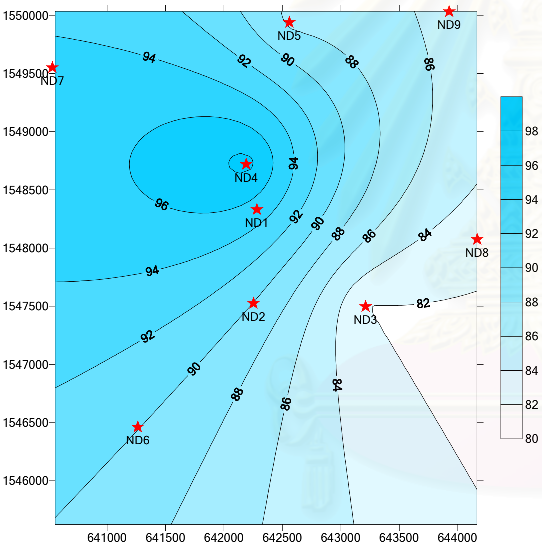
Sodium (18 Aug. 01)



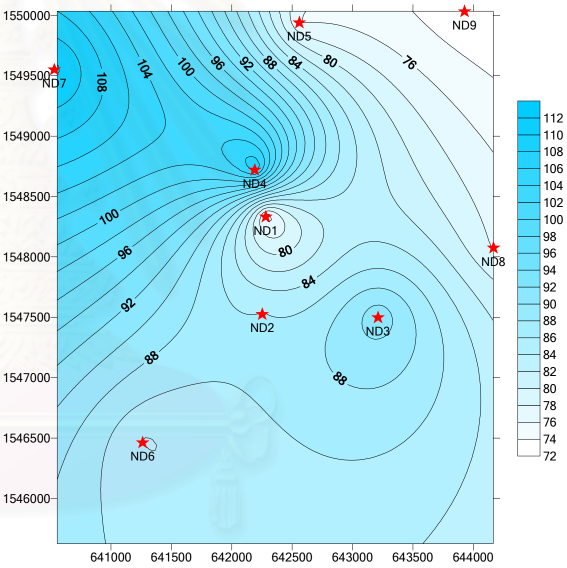
Sodium (28 Oct. 01)



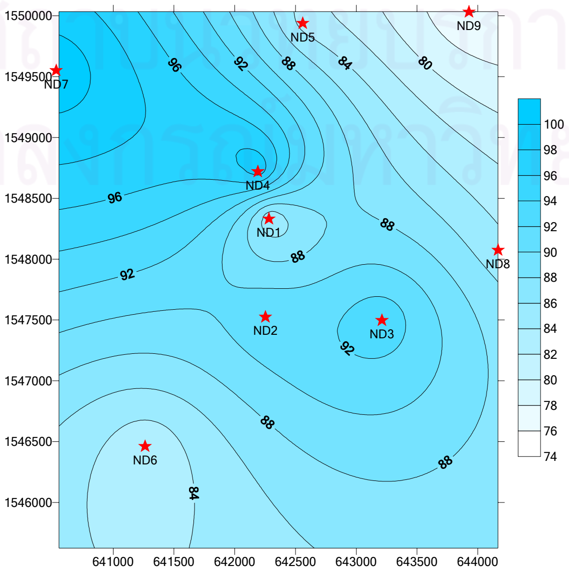
Sodium (27 Jan. 02)



Sodium (27 Mar. 02)



Sodium (27 Jul. 02)



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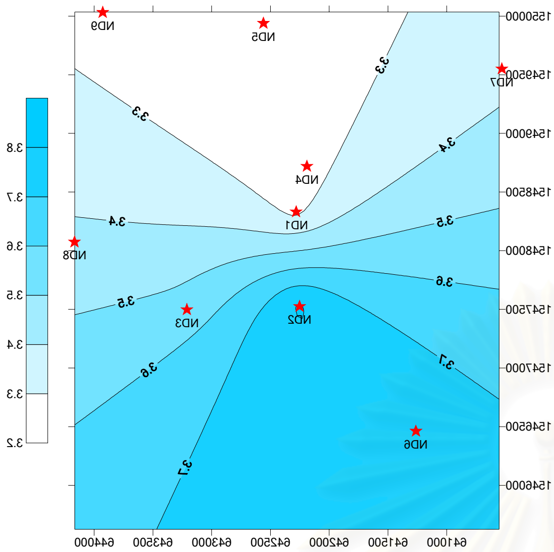
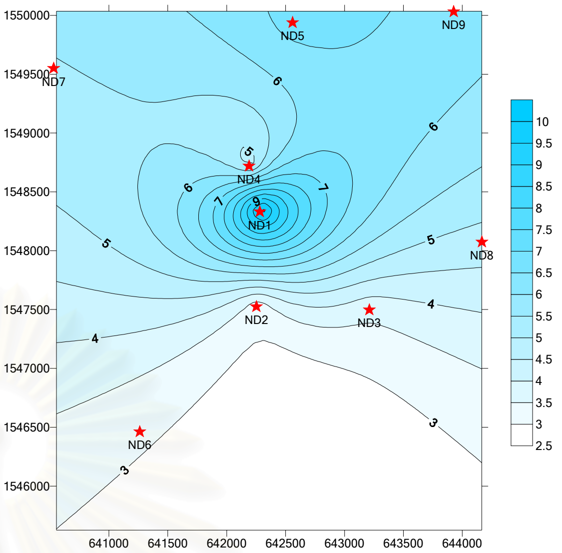
Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

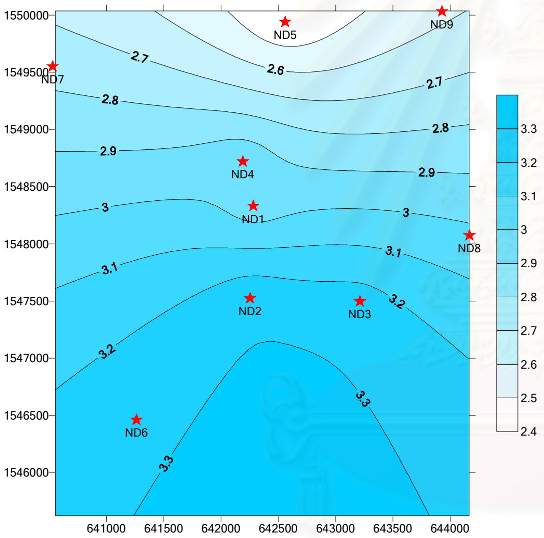
Potassium (18 Aug. 01)



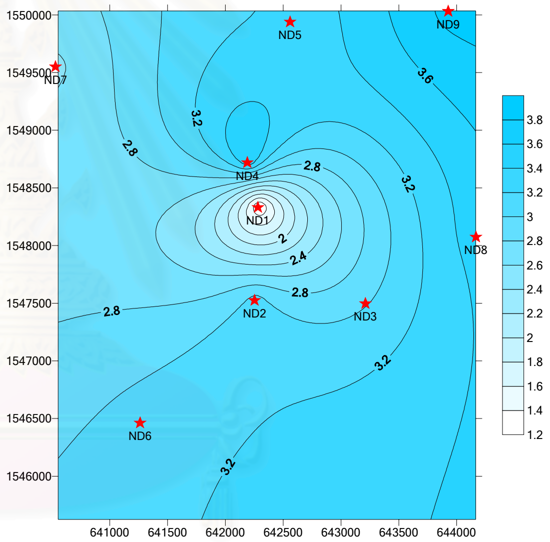
Potassium (28 Oct. 01)



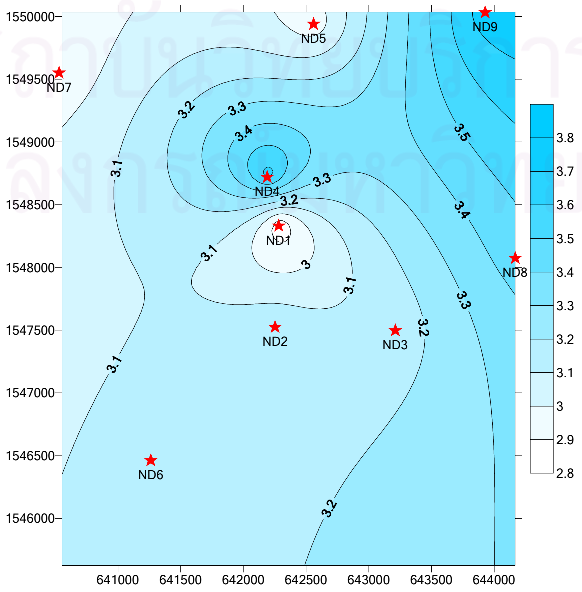
Potassium (27 Jan. 02)



Potassium (27 Mar. 02)

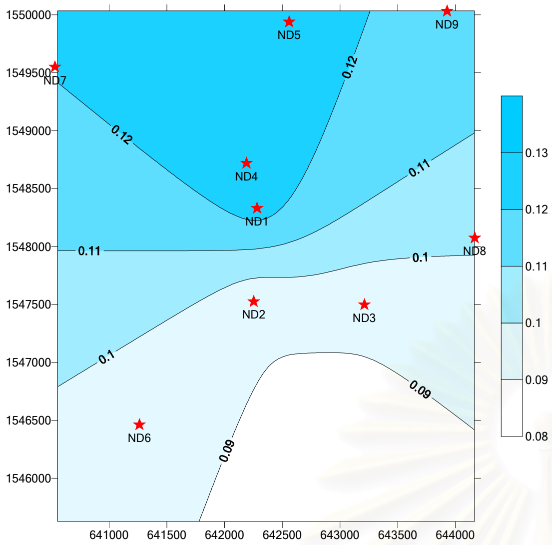


Potassium (27 Jul. 02)

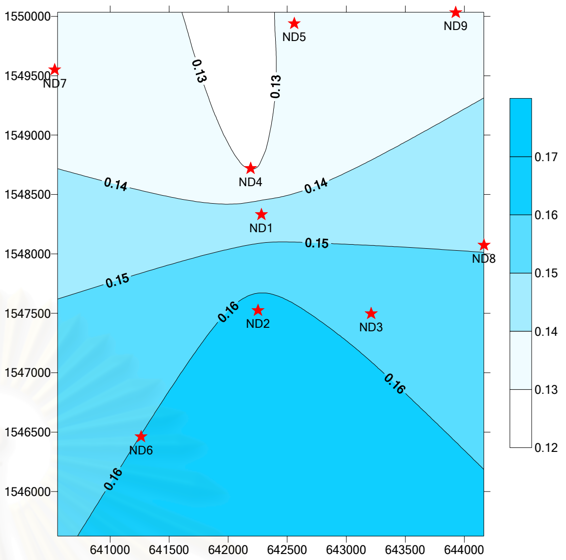


Appendix III.2 Contour line of chemical analysis: deep well water (cont.)

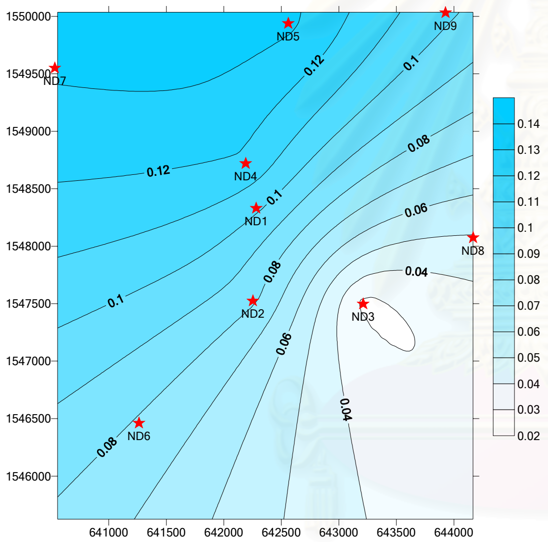
Copper (18 Aug. 01)



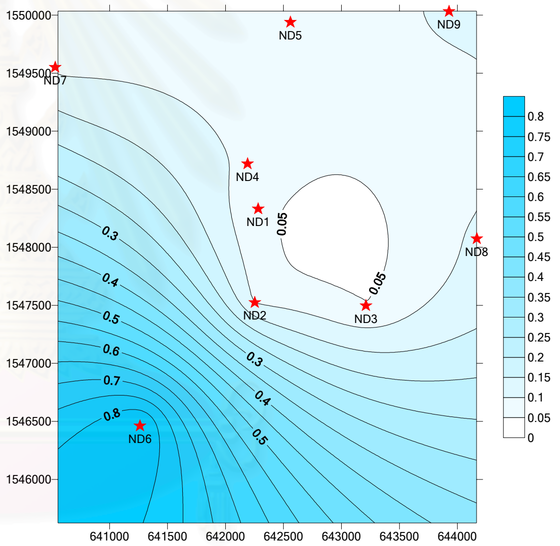
Copper (28 Oct. 01)



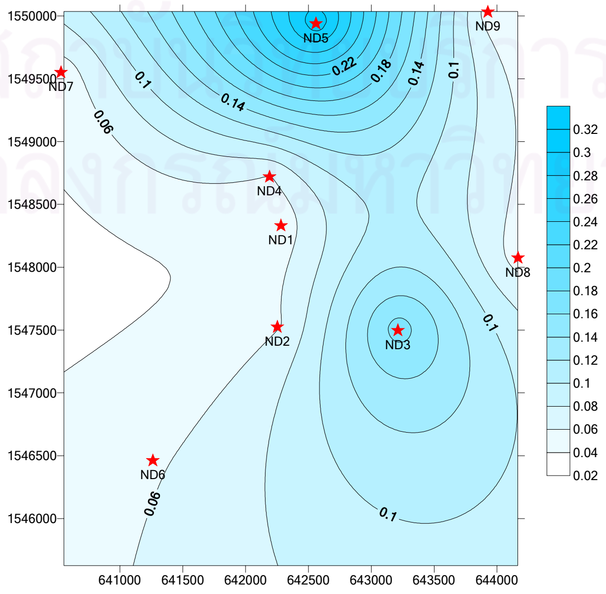
Copper (27 Jan. 02)



Copper (27 Mar. 02)



Copper (27 Jul. 02)



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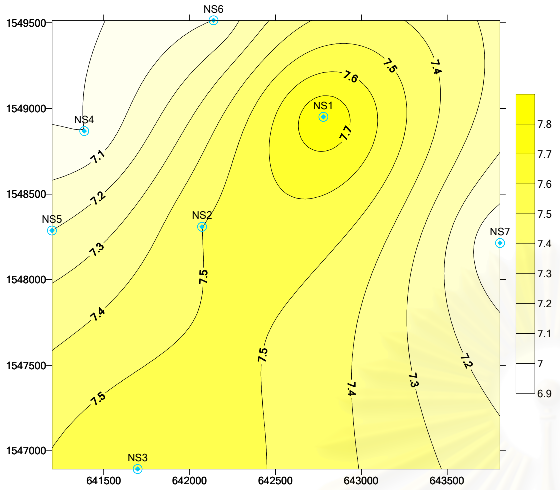
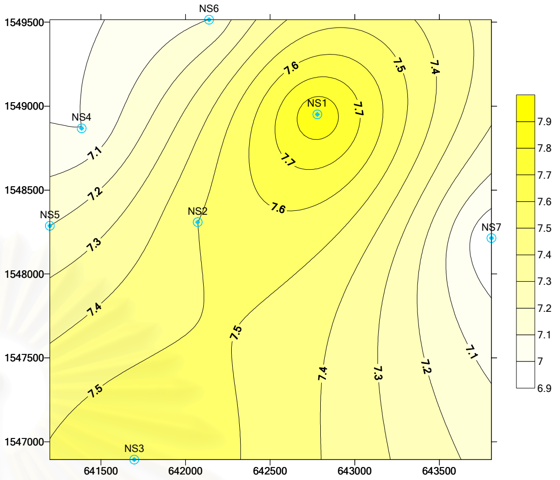
Appendix III.3 Contour line of chemical analysis: surface water

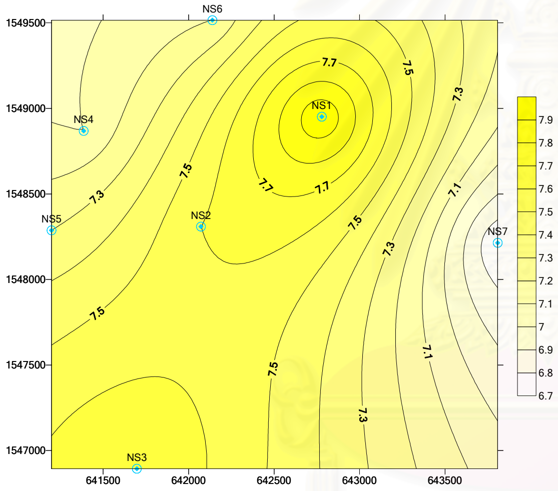
pH (18 Aug. 01)



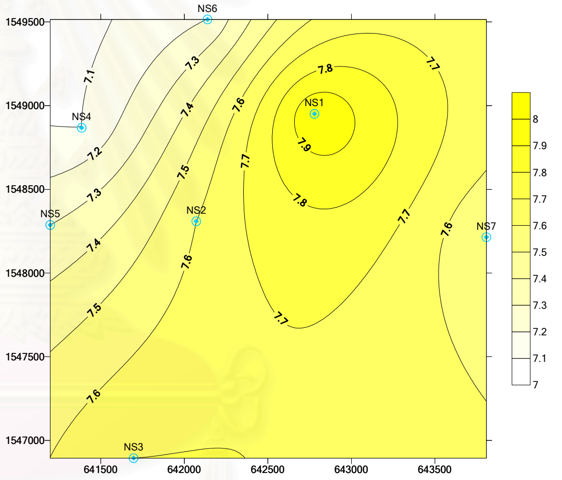
pH (28 Oct. 01)



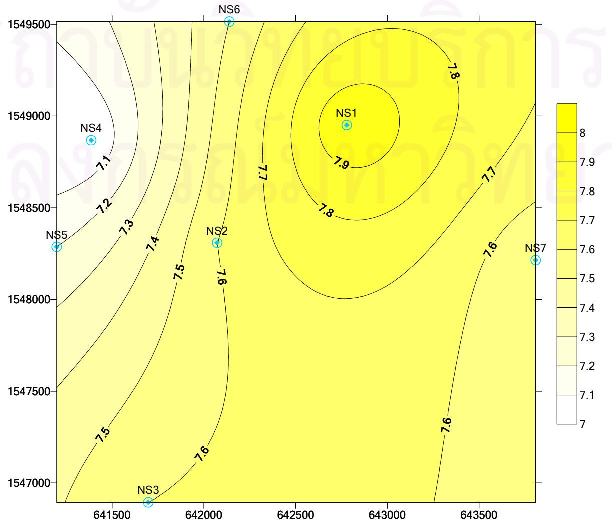
pH (27 Jan. 02)



pH (27 Mar. 02)



pH (27 Jul. 02)



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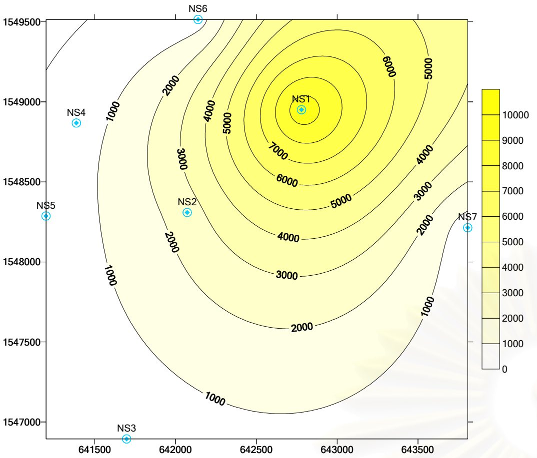
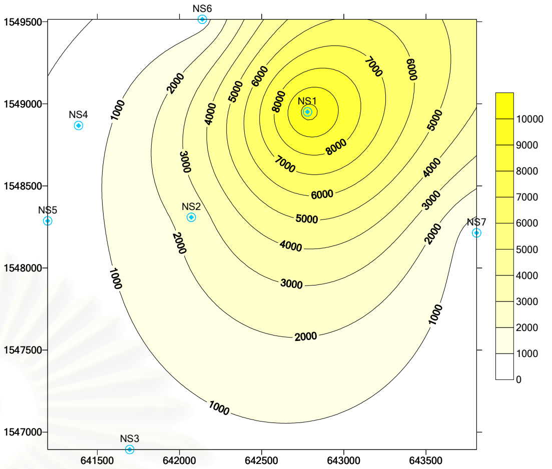
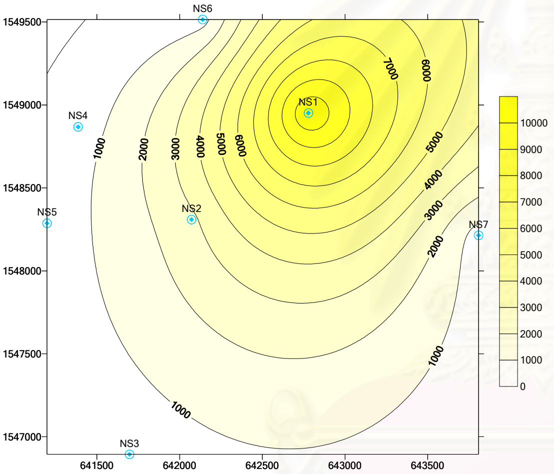
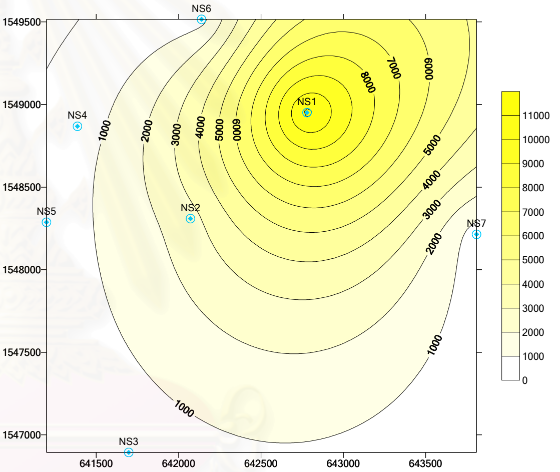
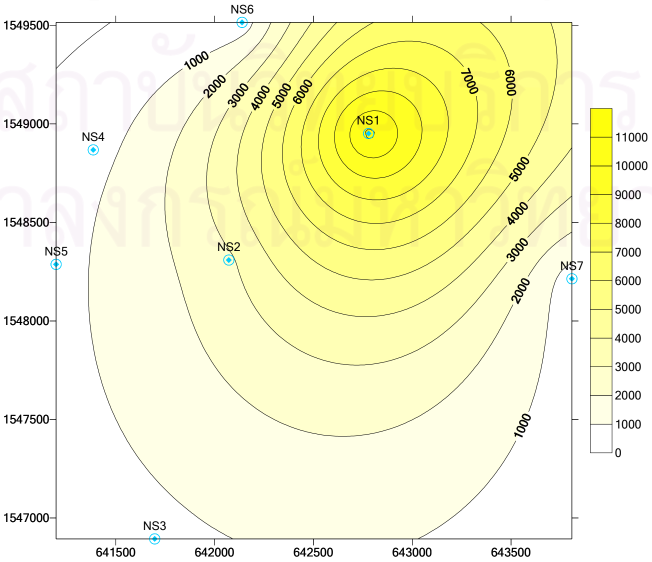
Appendix III.3 Contour line of chemical analysis: surface water (cont.)


Electrical Conductivity (18 Aug. 01)


Electrical Conductivity (28 Oct. 01)


Electrical Conductivity (27 Jan. 02)


Electrical Conductivity (27 Mar. 02)


Electrical Conductivity (27 Jul. 02)

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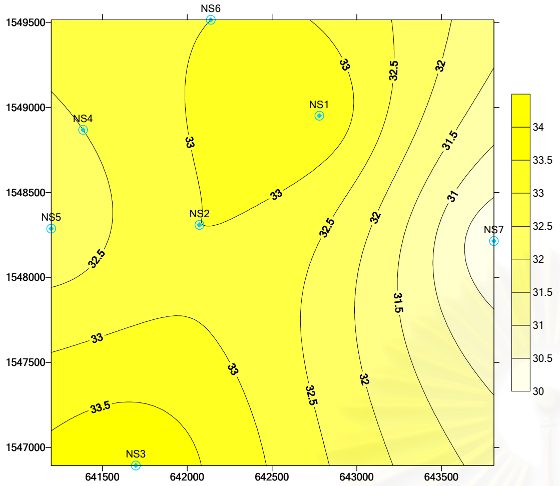
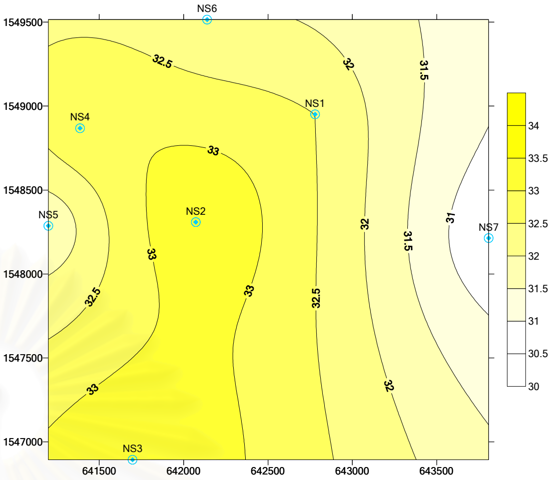
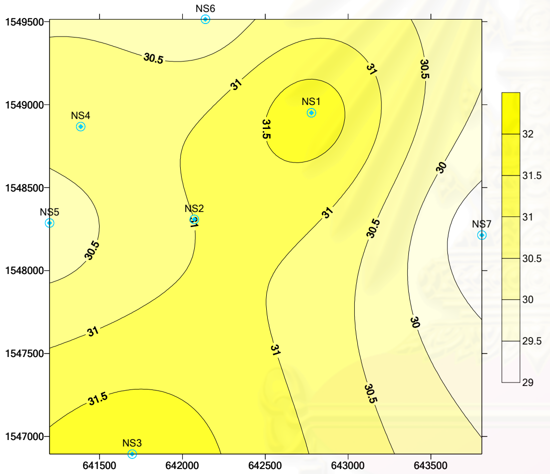
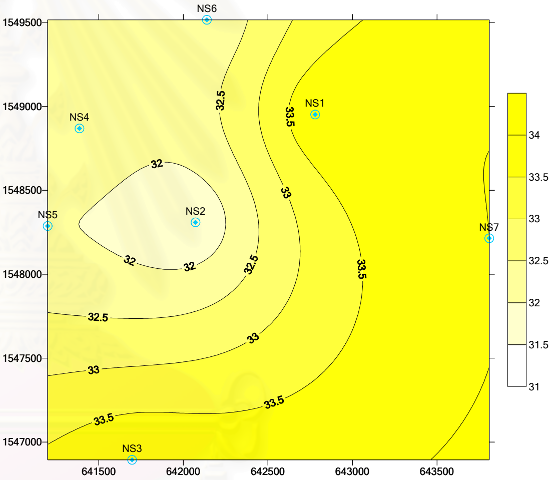
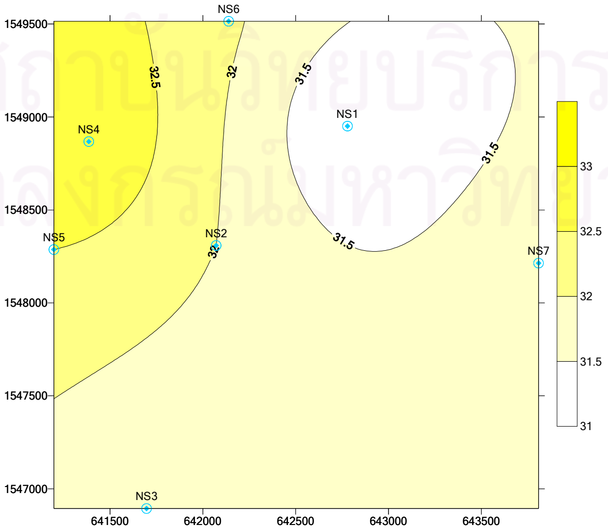
Appendix III.3 Contour line of chemical analysis: surface water (cont.)


Temperature (18 Aug. 01)


Temperature (28 Oct. 01)

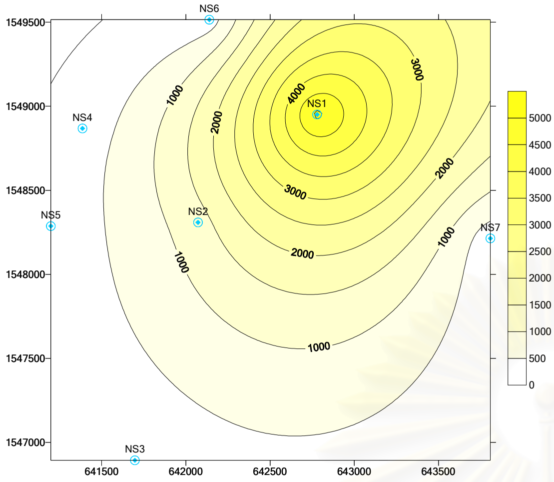

Temperature (27 Jan. 02)


Temperature (27 Mar. 02)

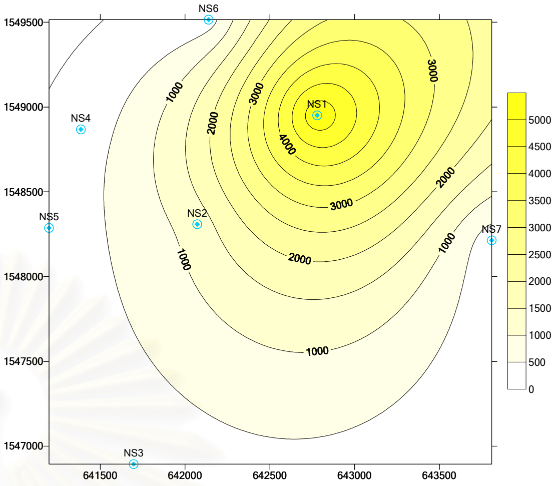

Temperature (27 Jul. 02)

Appendix III.3 Contour line of chemical analysis: surface water (cont.)

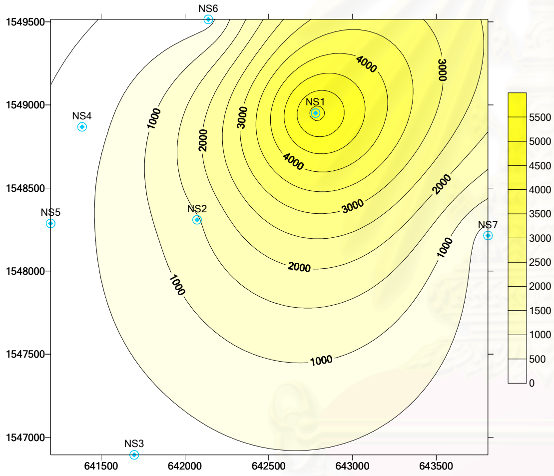
Total Dissolved Soild (18 Aug. 01)



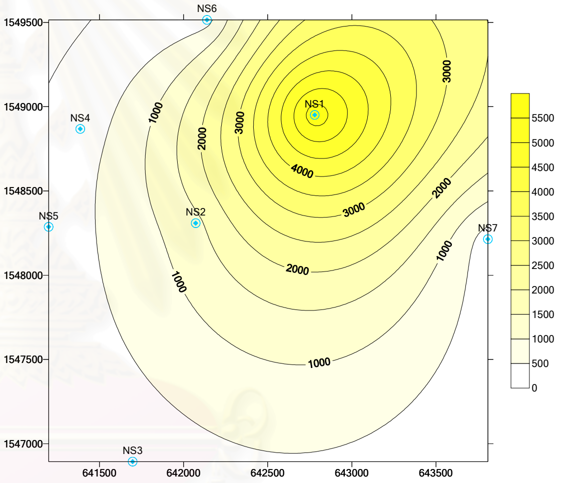
Total Dissolved Soild (28 Oct. 01)



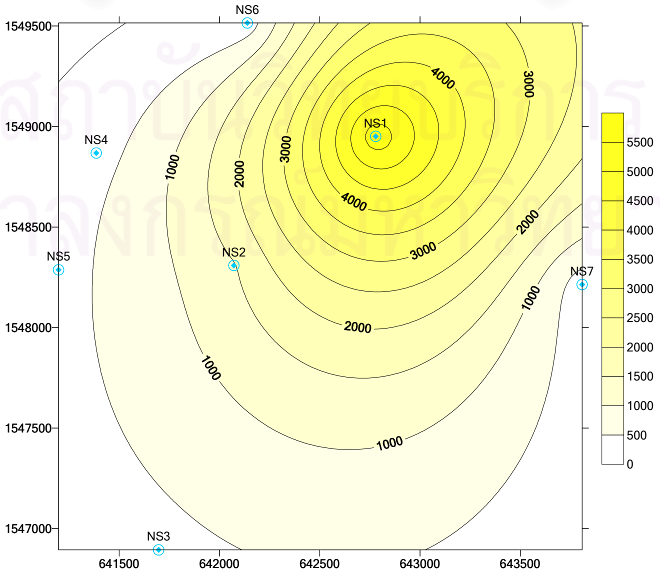
Total Dissolved Soild (27 Jan. 02)



Total Dissolved Soild (27 Mar. 02)



Total Dissolved Soild (27 Jul. 02)



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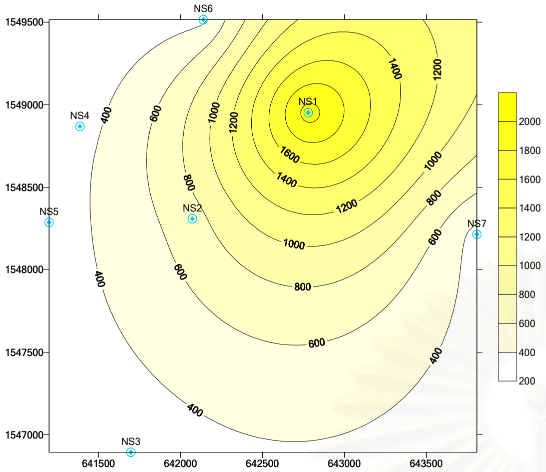
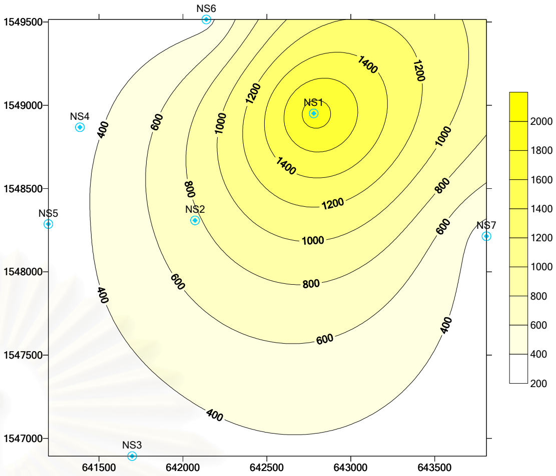
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

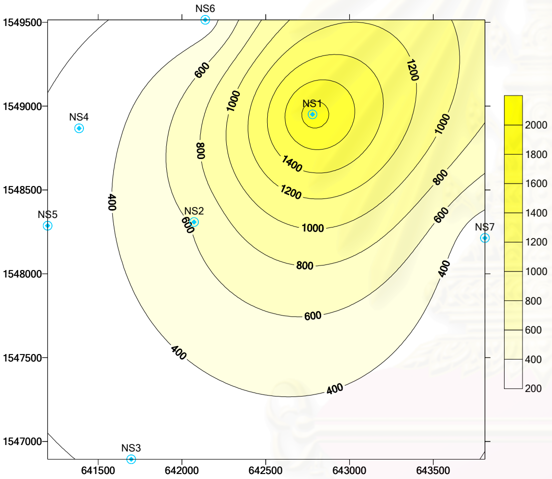
Total Hardness (18 Aug. 01)



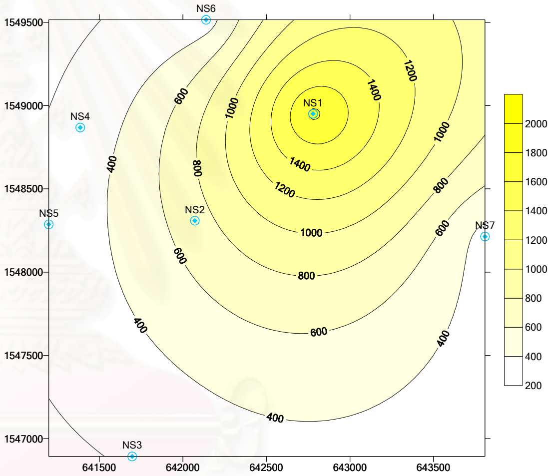
Total Hardness (28 Oct. 01)



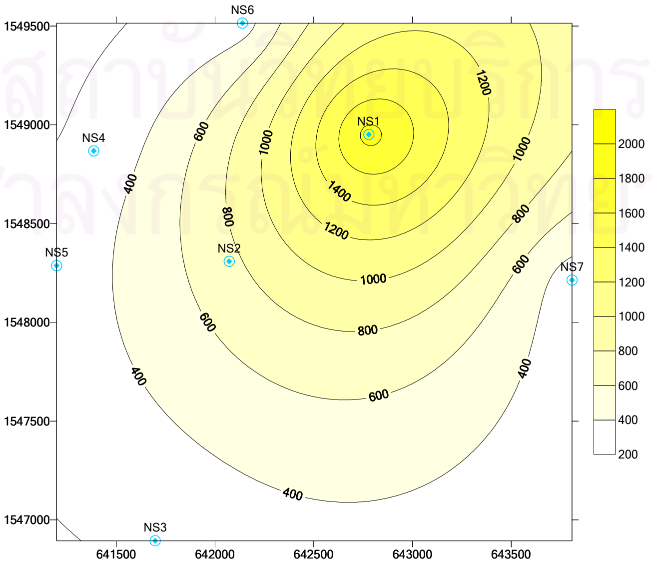
Total Hardness (27 Jan. 02)



Total Hardness (27 Mar. 02)



Total Hardness (27 Jul. 02)



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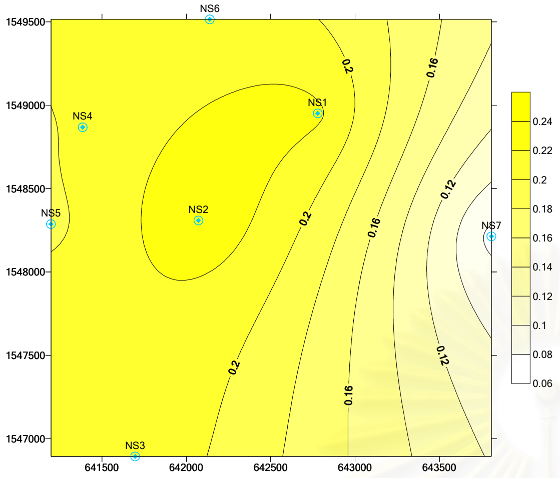
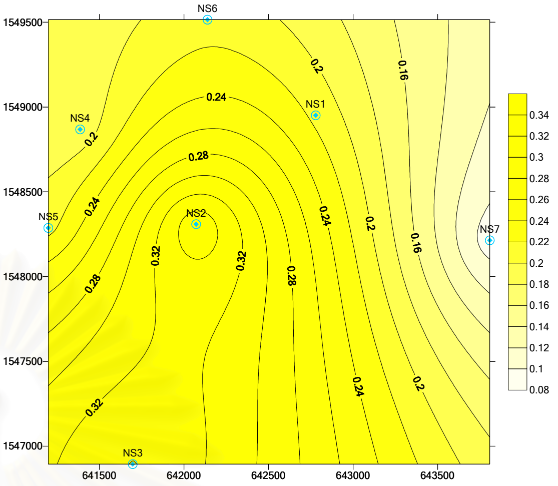
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

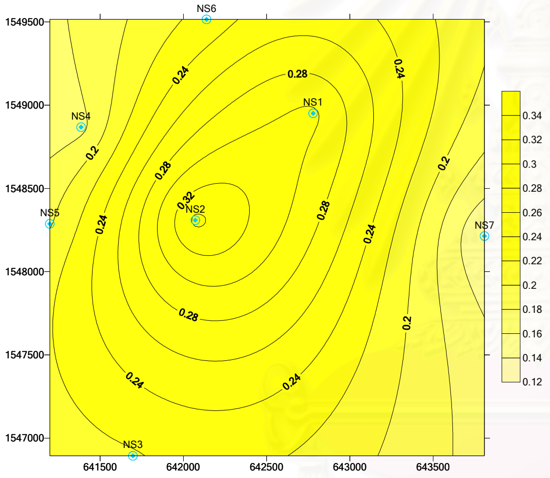
Total Chromium (18 Aug. 01)



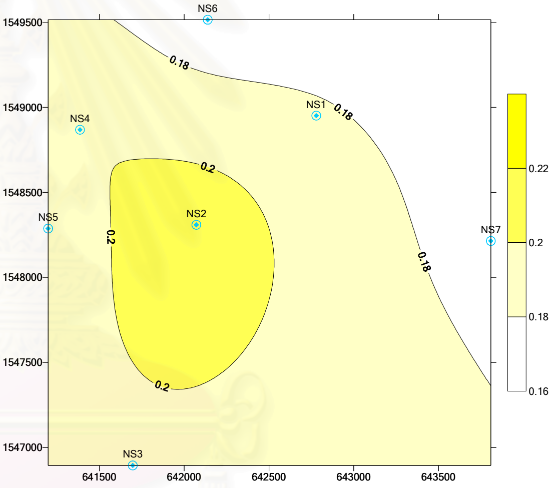
Total Chromium (28 Oct. 01)



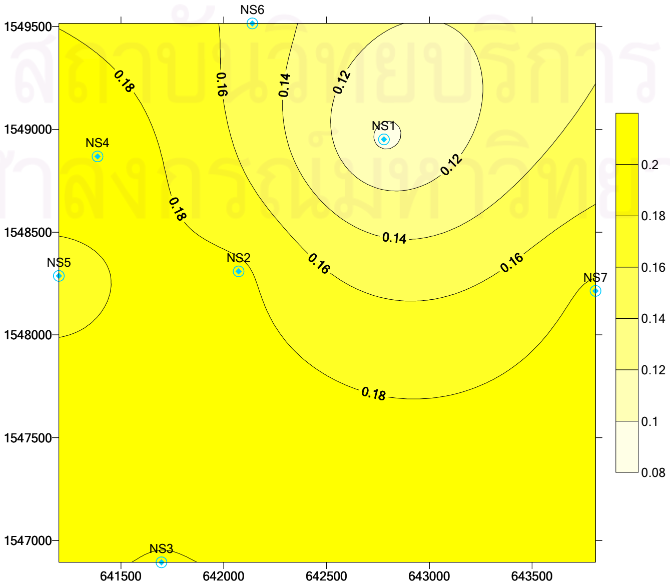
Total Chromium (27 Jan. 02)



Total Chromium (27 Mar. 02)



Total Chromium (27 Jul. 02)



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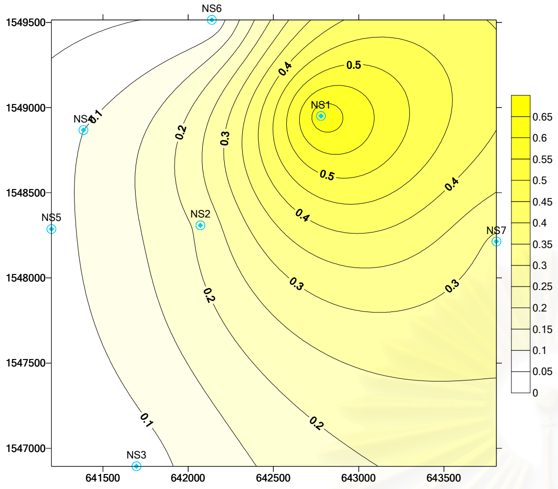
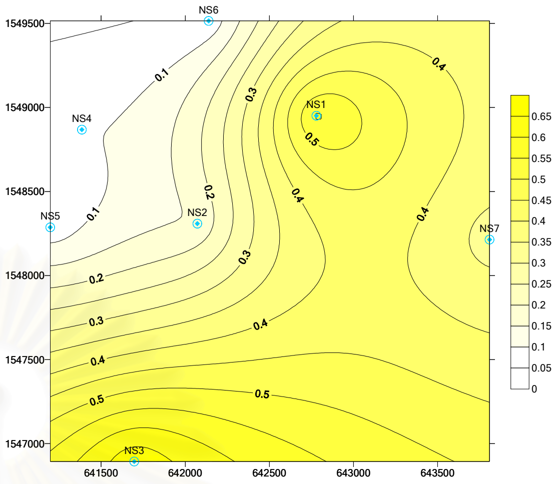
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

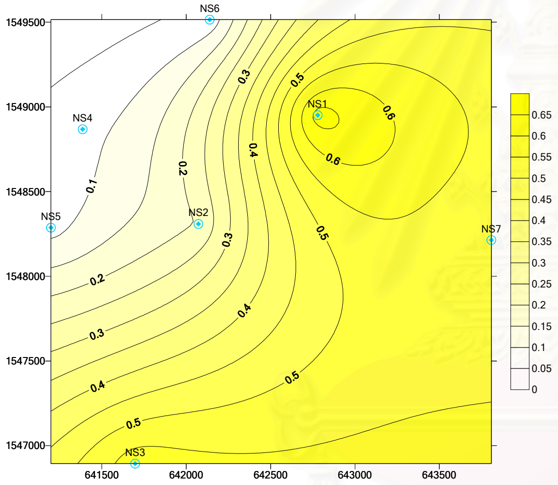
Manganese (18 Aug. 01)



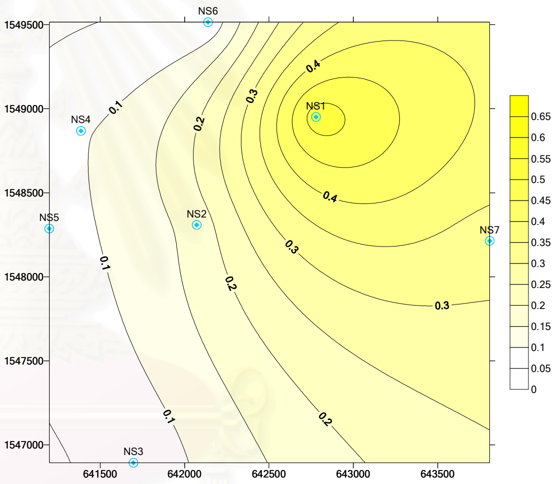
Manganese (28 Oct. 01)



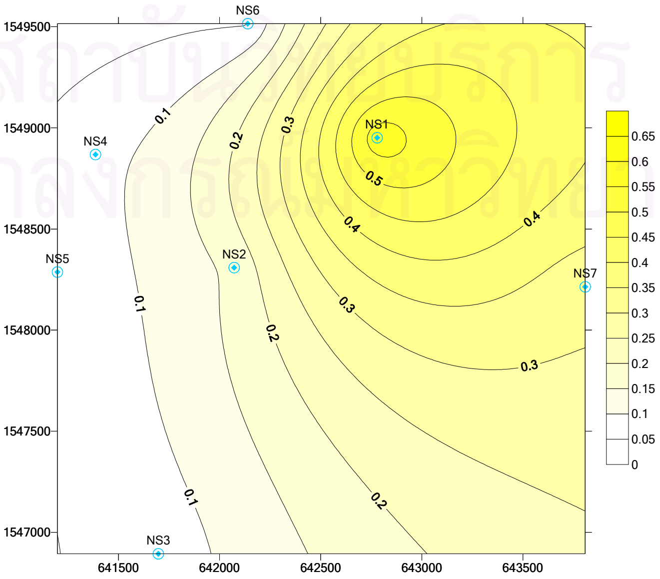
Manganese (27 Jan. 02)



Manganese (27 Mar. 02)



Manganese (27 Jul. 02)



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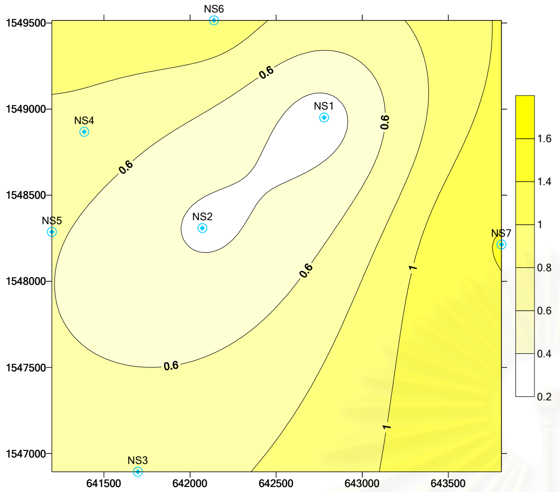
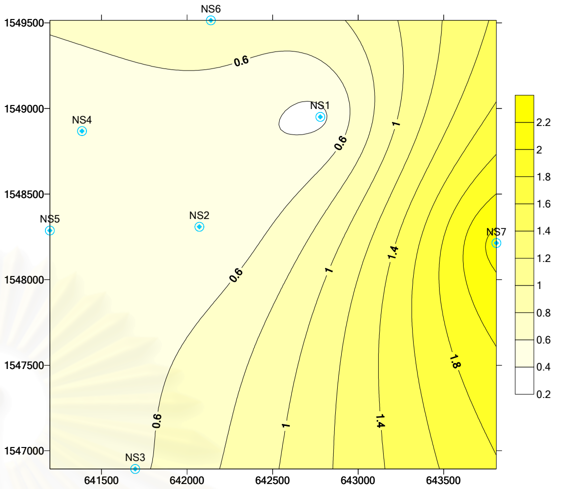
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

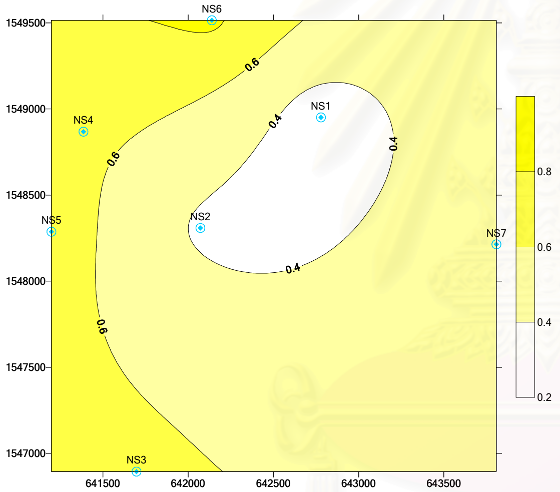
Total Iron (18 Aug. 01)



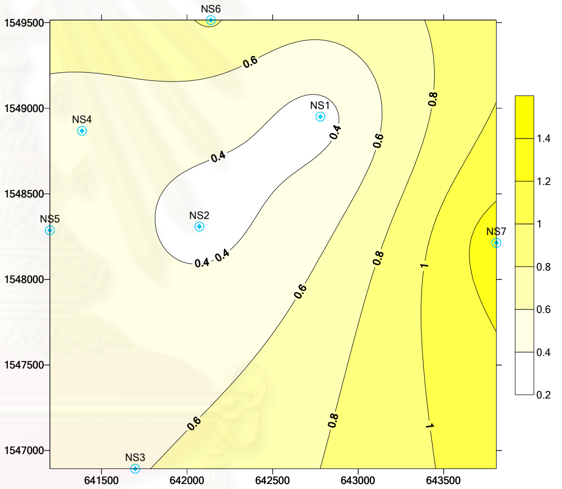
Total Iron (28 Oct. 01)



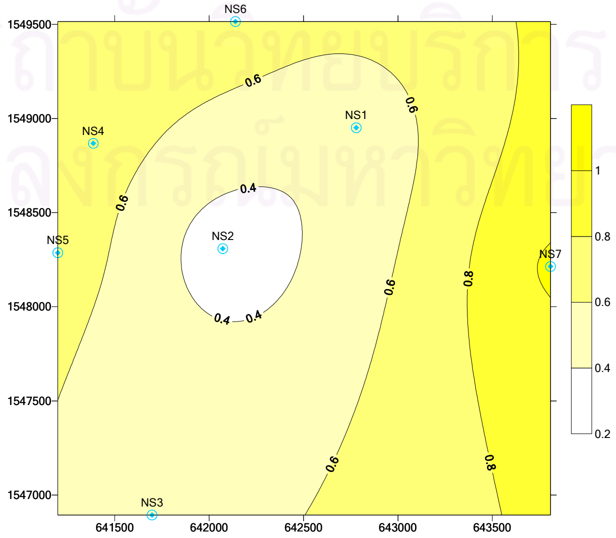
Total Iron (27 Jan. 02)



Total Iron (27 Mar. 02)



Total Iron (27 Jul. 02)



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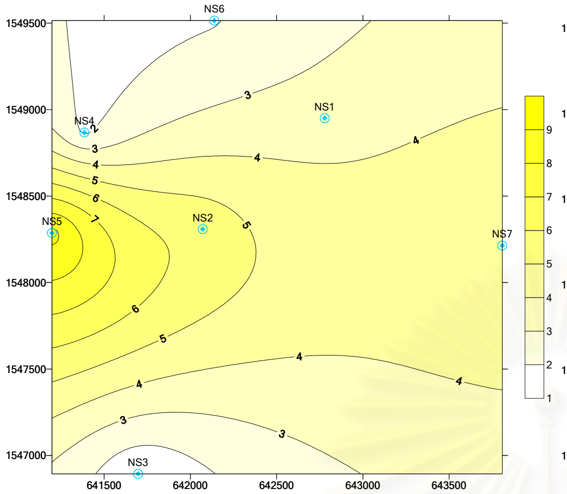
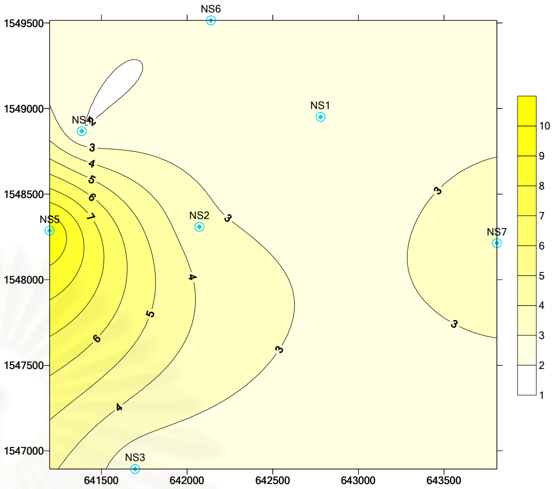
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

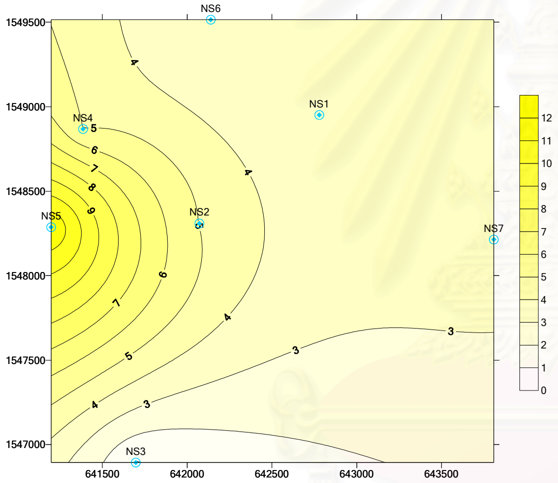
Arsenic (18 Aug. 01)



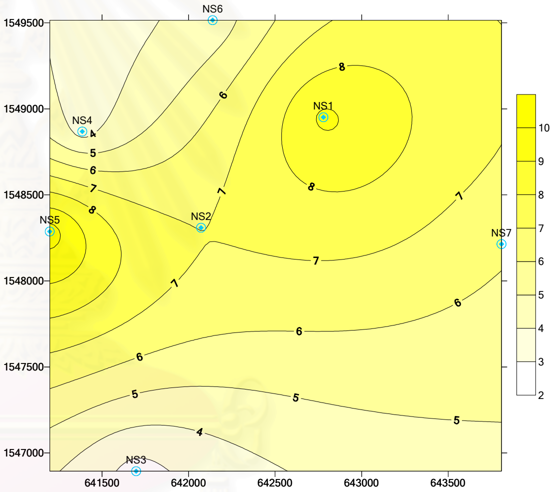
Arsenic (28 Oct. 01)



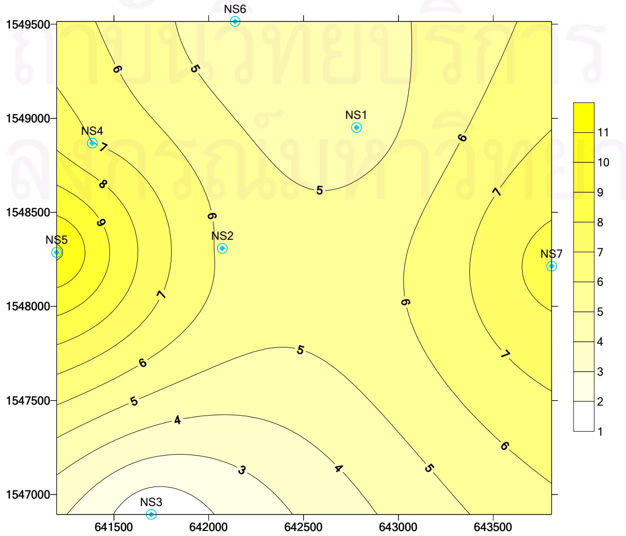
Arsenic (27 Jan. 02)



Arsenic (27 Mar. 02)



Arsenic (27 Jul. 02)



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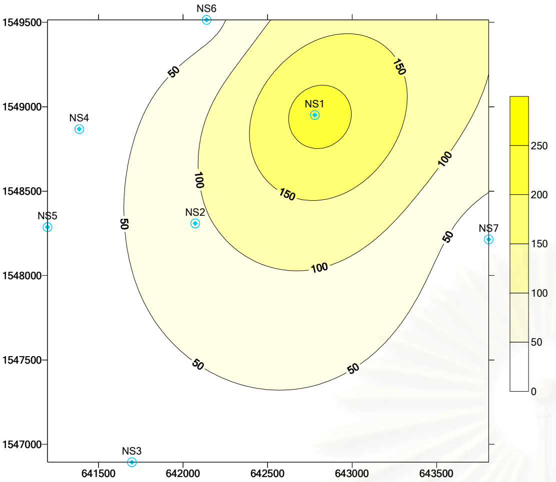
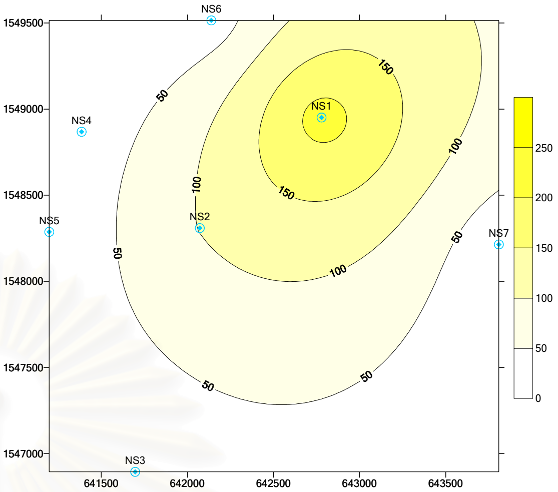
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

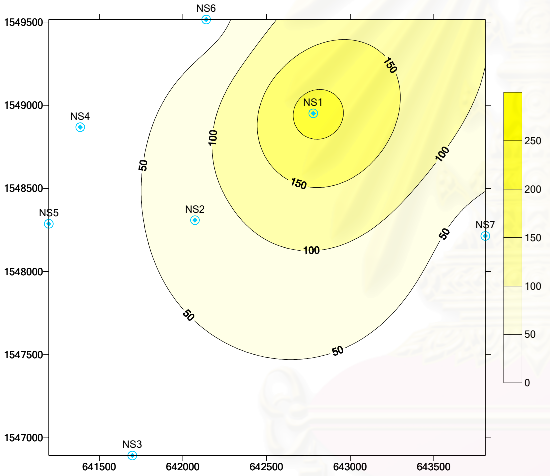
Magnesium (18 Aug. 01)



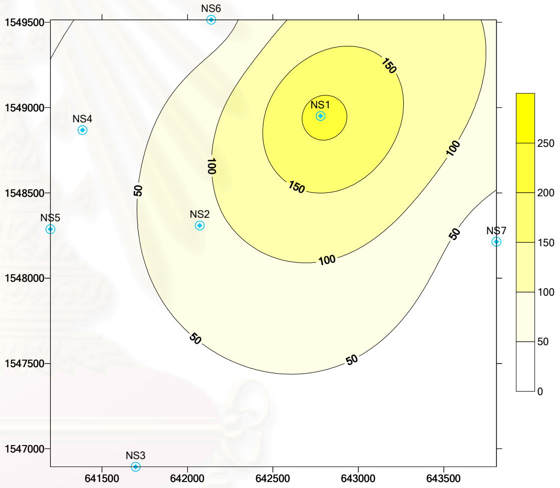
Magnesium (28 Oct. 01)



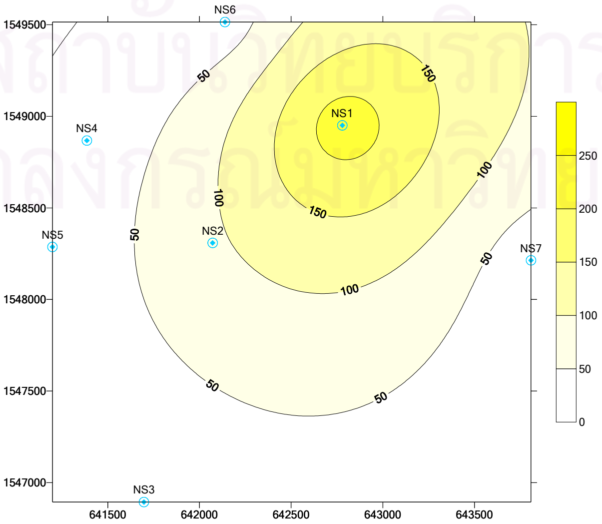
Magnesium (27 Jan. 02)



Magnesium (27 Mar. 02)



Magnesium (27 Jul. 02)



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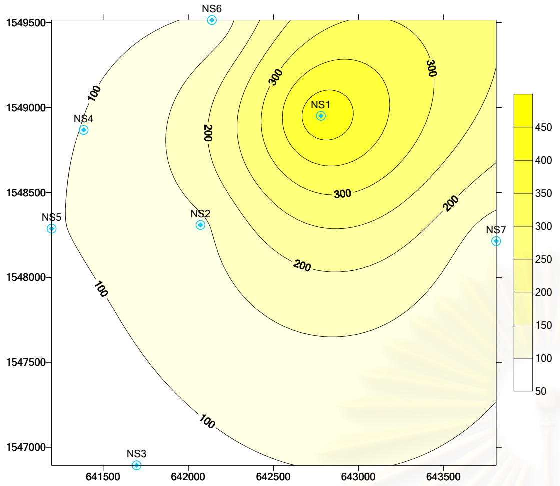
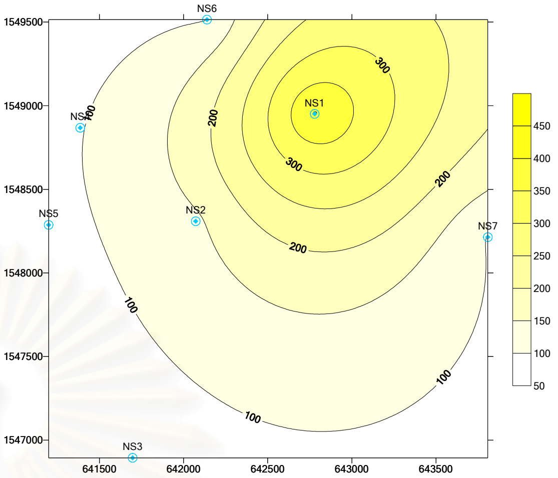
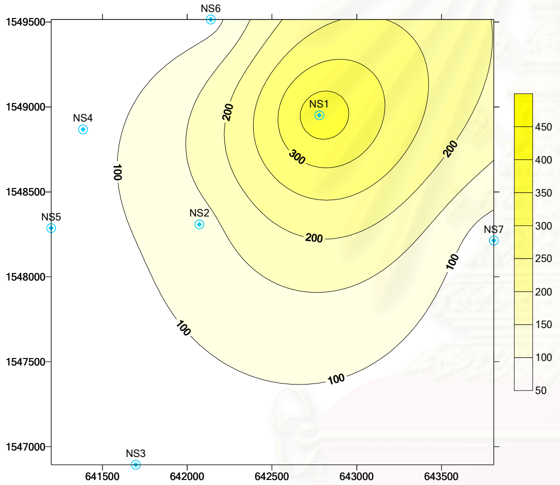
Appendix III.3 Contour line of chemical analysis: surface water (cont.)



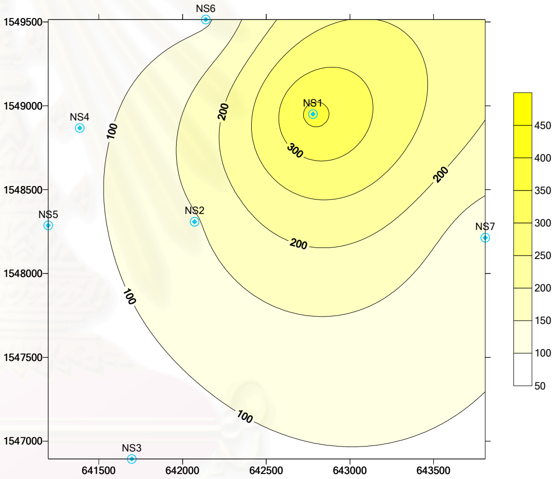
Calcium (18 Aug. 01)



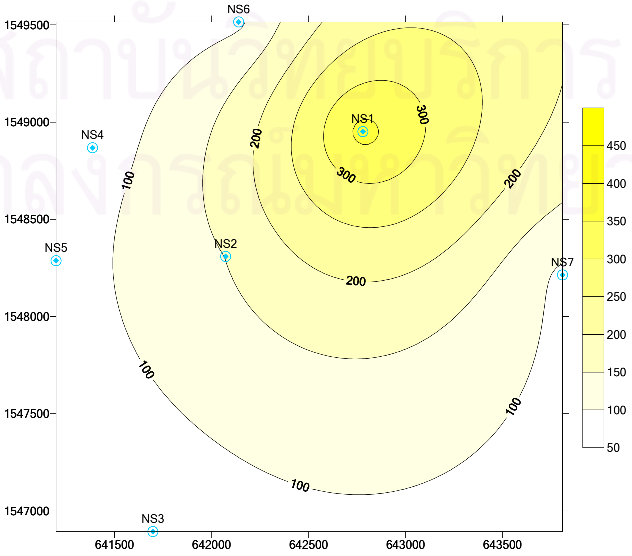
Calcium (28 Oct. 01)



Calcium (27 Jan. 02)



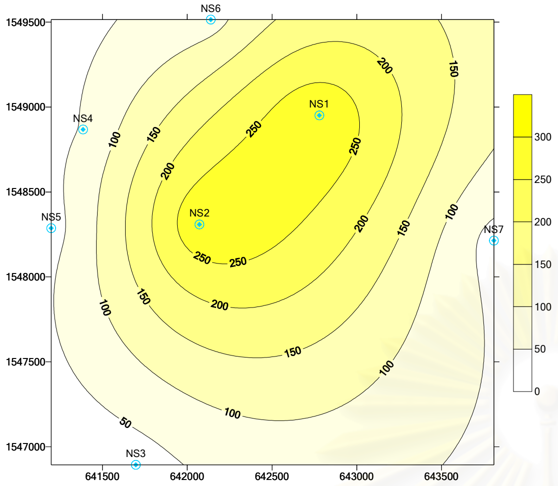
Calcium (27 Mar. 02)



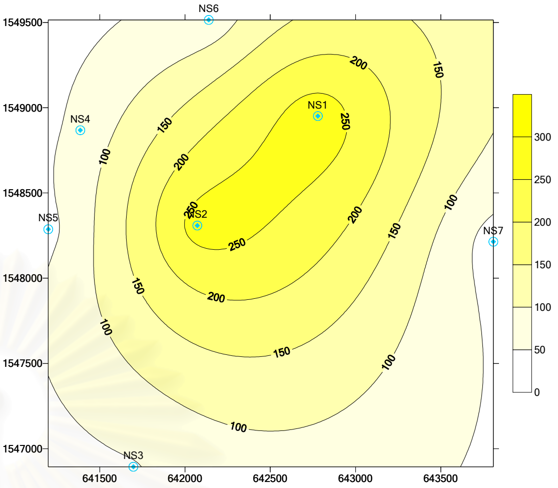
Calcium (27 Jul. 02)

Appendix III.3 Contour line of chemical analysis: surface water (cont.)

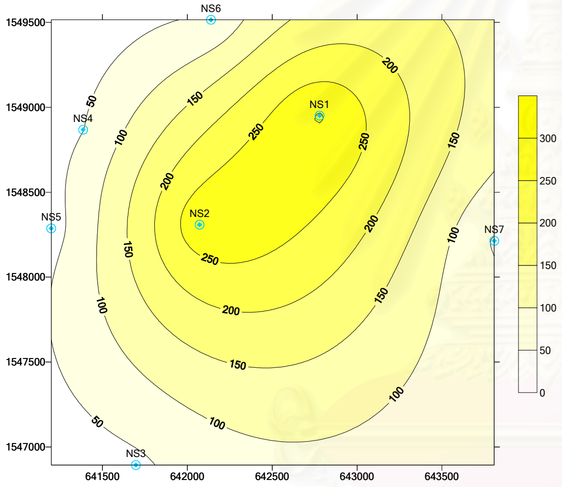
Sodium (18 Aug. 01)



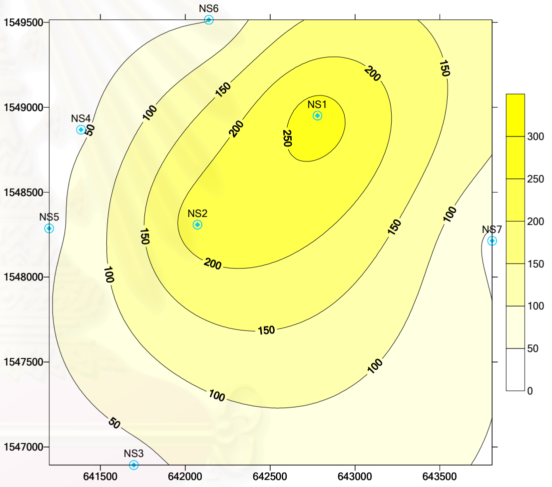
Sodium (28 Oct. 01)



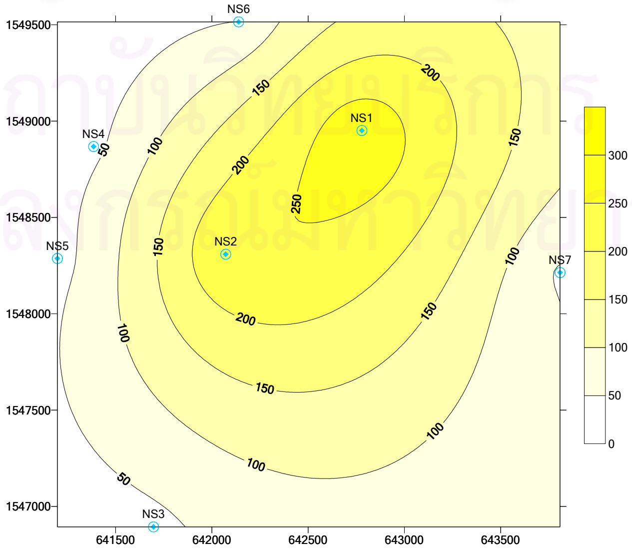
Sodium (27 Jan. 02)



Sodium (27 Mar. 02)



Sodium (27 Jul. 02)



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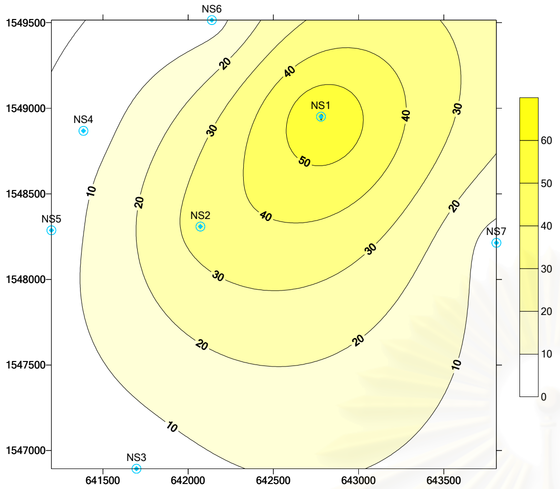
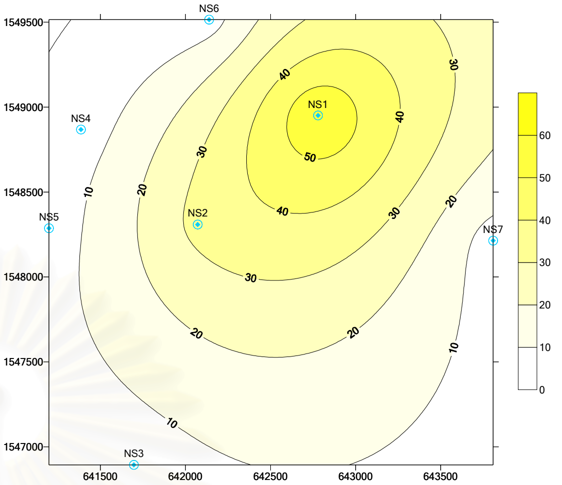
Appendix III.3 Contour line of chemical analysis: surface water (cont.)

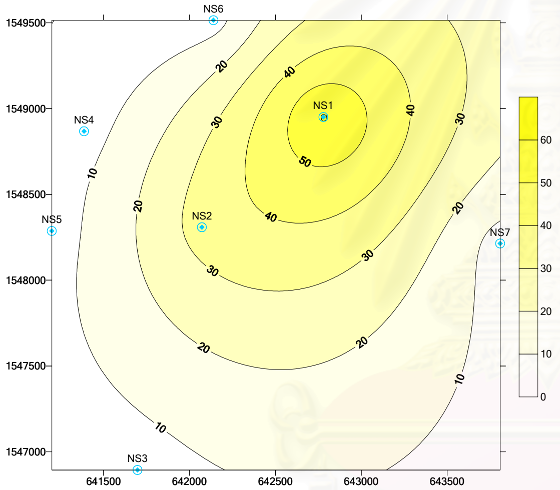
Potassium (18 Aug. 01)



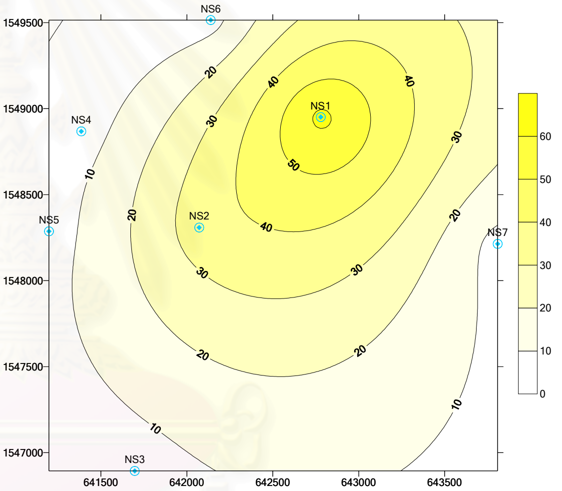
Potassium (28 Oct. 01)



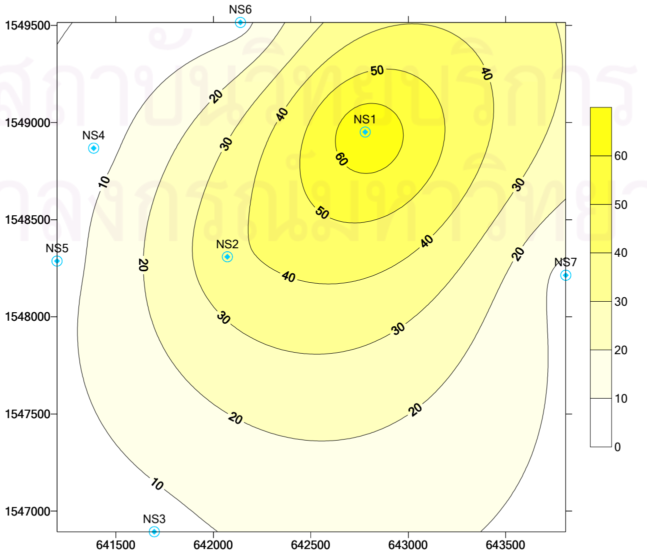
Potassium (27 Jan. 02)



Potassium (27 Mar. 02)



Potassium (27 Jul. 02)



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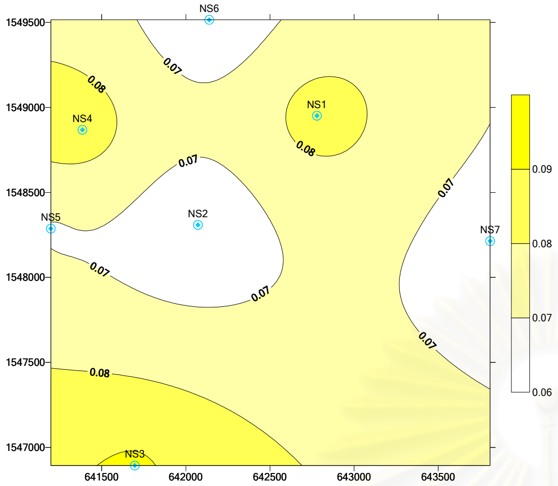
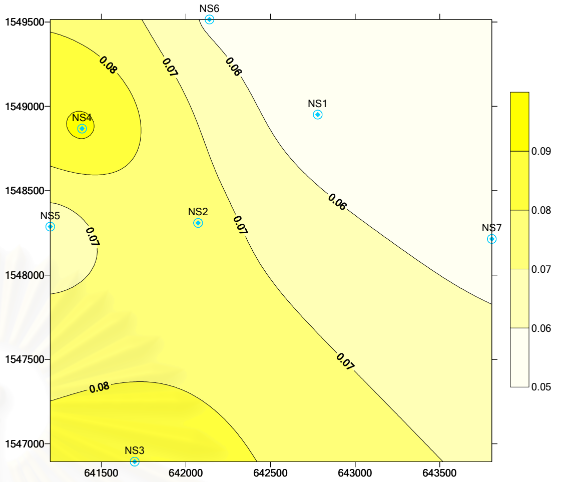
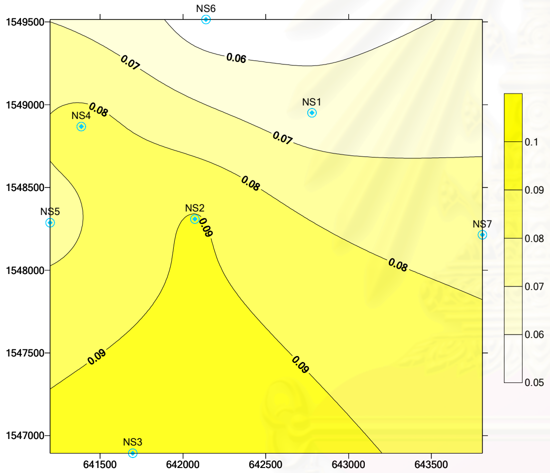
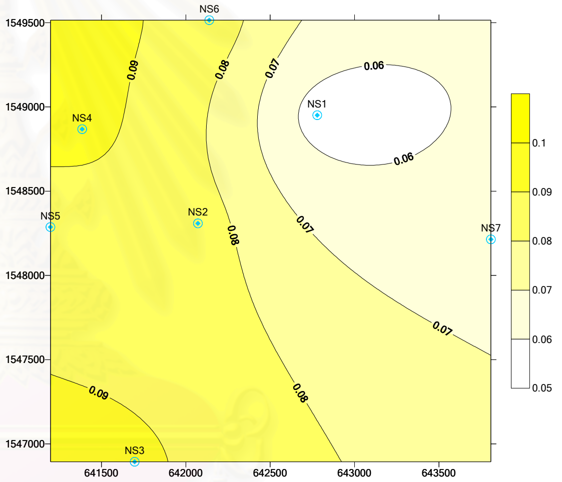
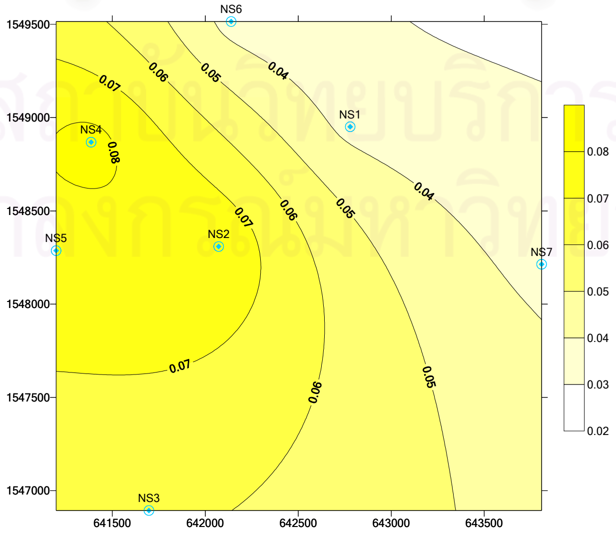
Appendix III.3 Contour line of chemical analysis: surface water (cont.)


Copper (18 Aug. 01)


Copper (28 Oct. 01)


Copper (27 Jan. 02)


Copper (27 Mar. 02)


Copper (27 Jul. 02)

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APPENDIX IV

RELATIONSHIP BETWEEN CHEMICAL ANALYSIS OF SHALLOW SUBSURFACE AND RAINFALL

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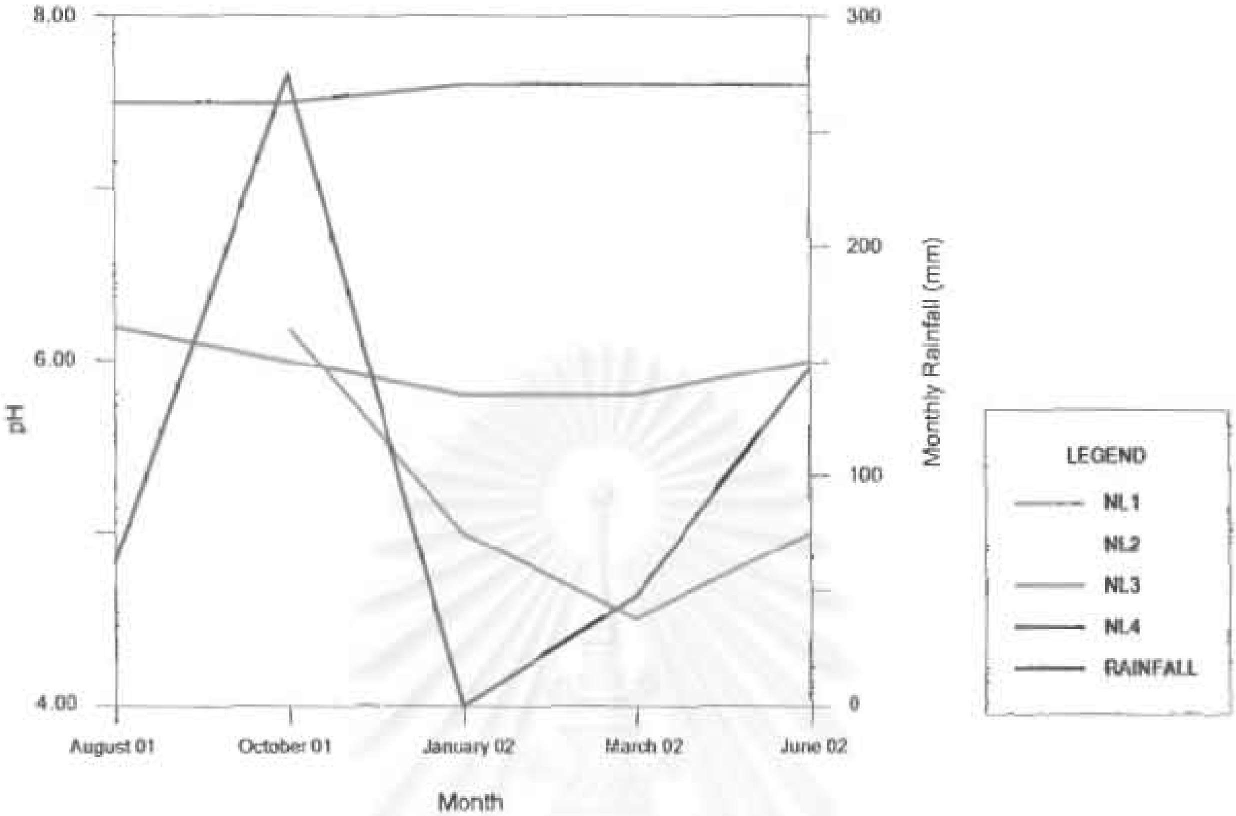
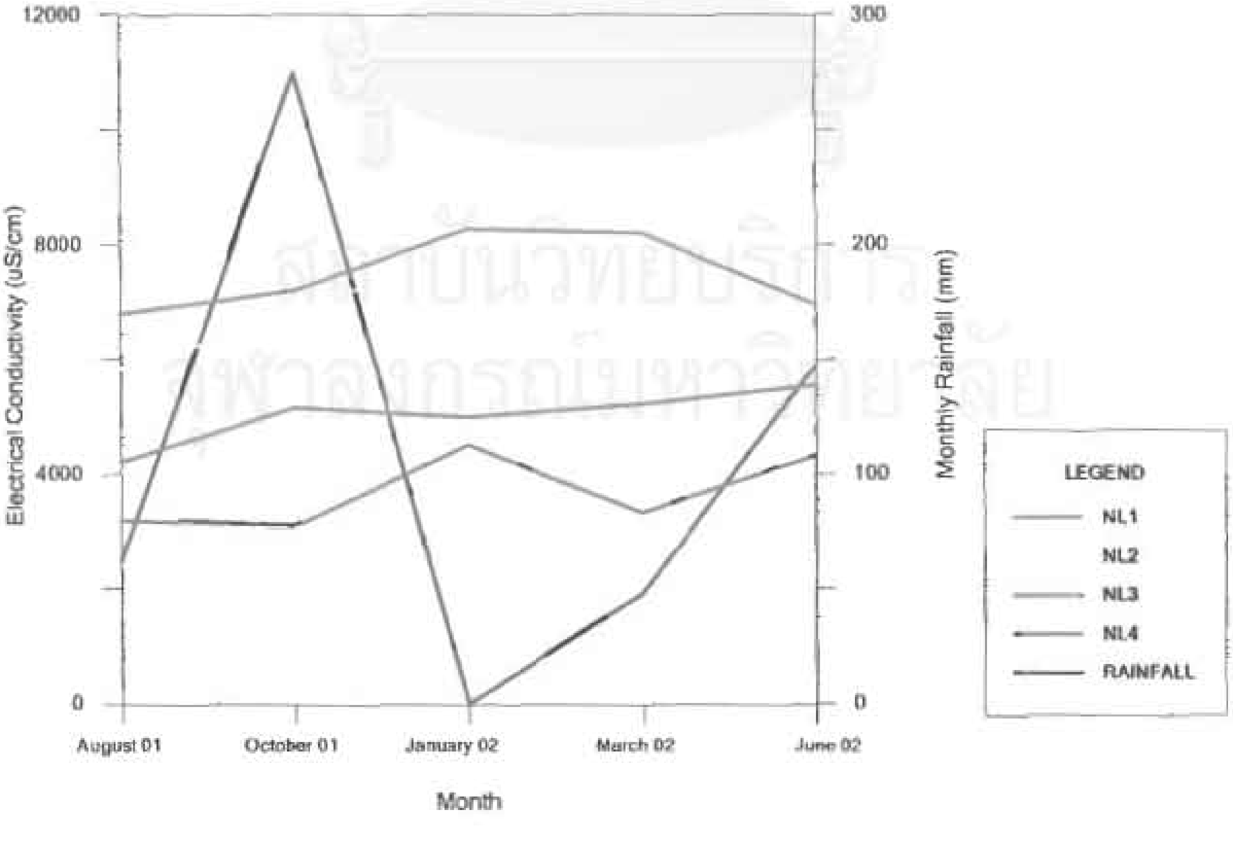
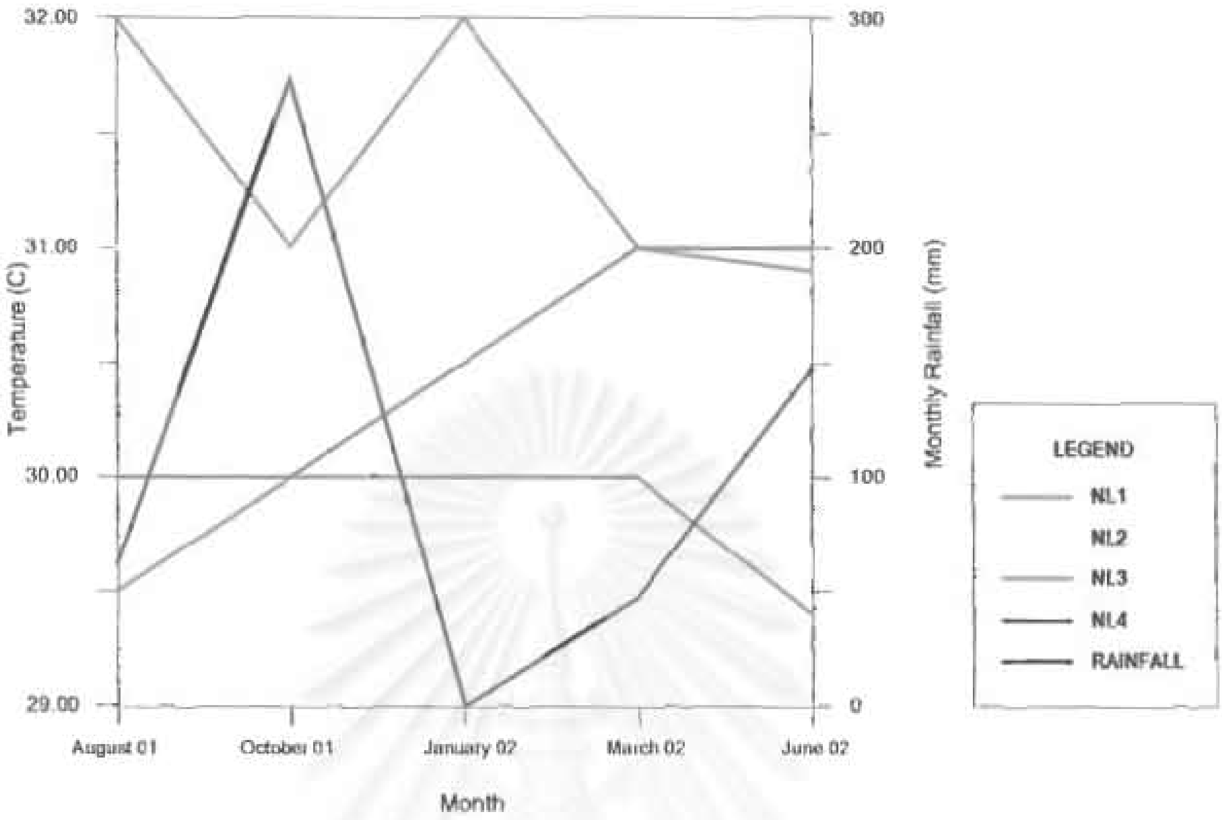


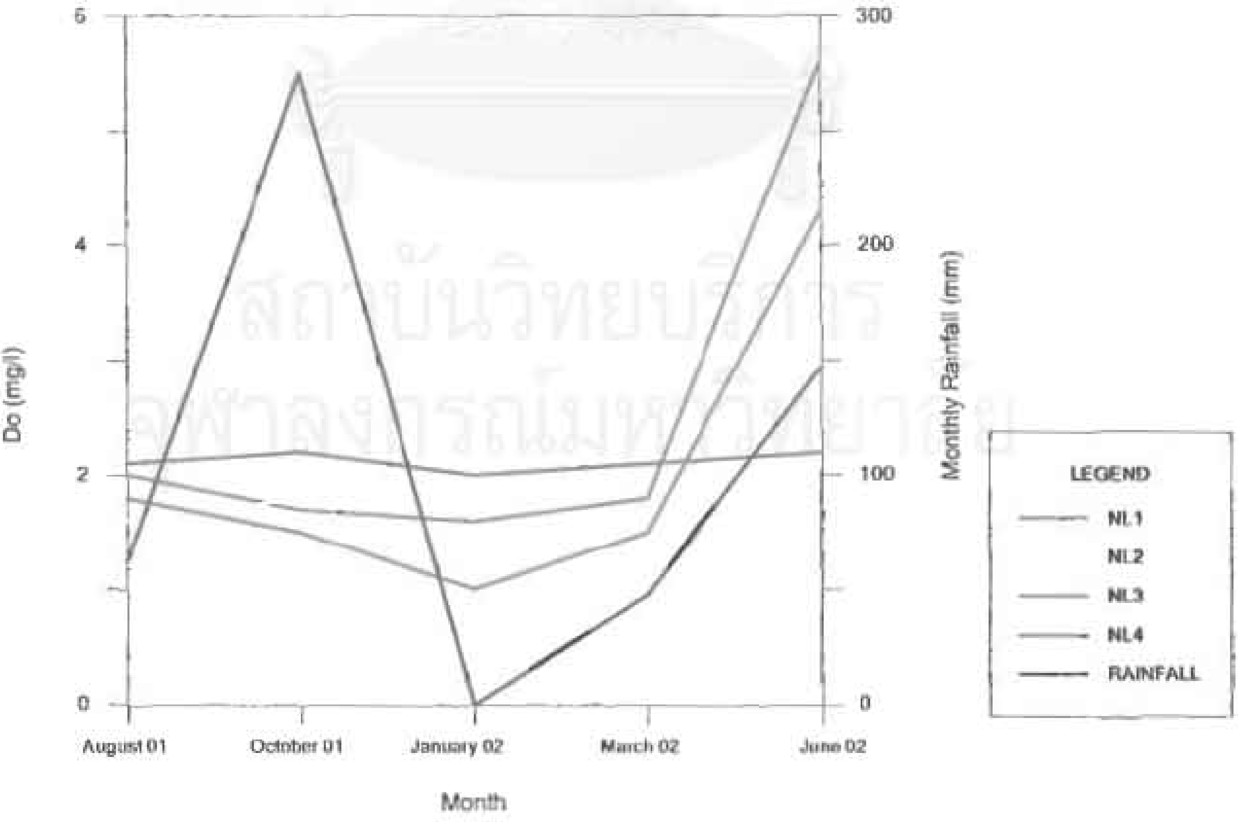
Appendix IV.2 Relation between Electrical Conductivity and Rainfall



สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย



Appendix IV.4 Relation between Do and Rainfall



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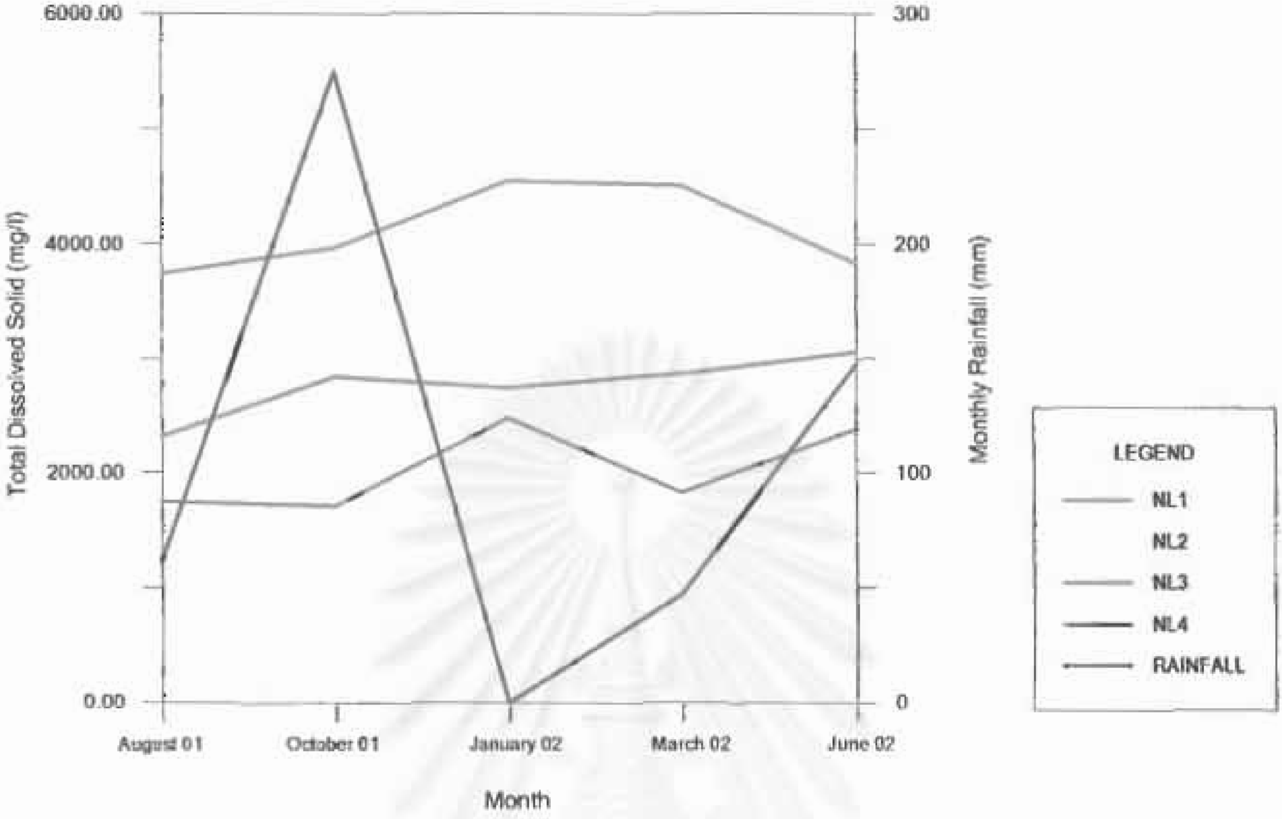
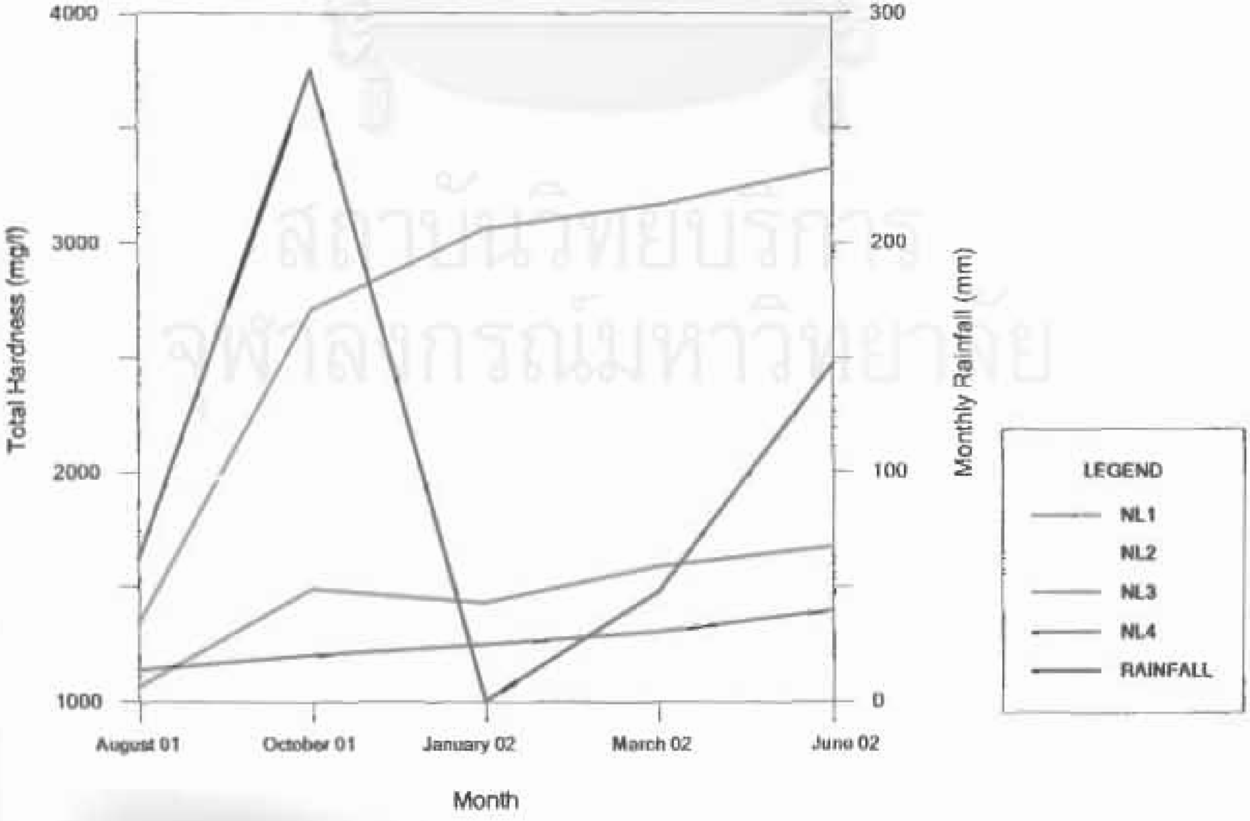


Appendix IV.6 Relation between Total Hardness and Rainfall



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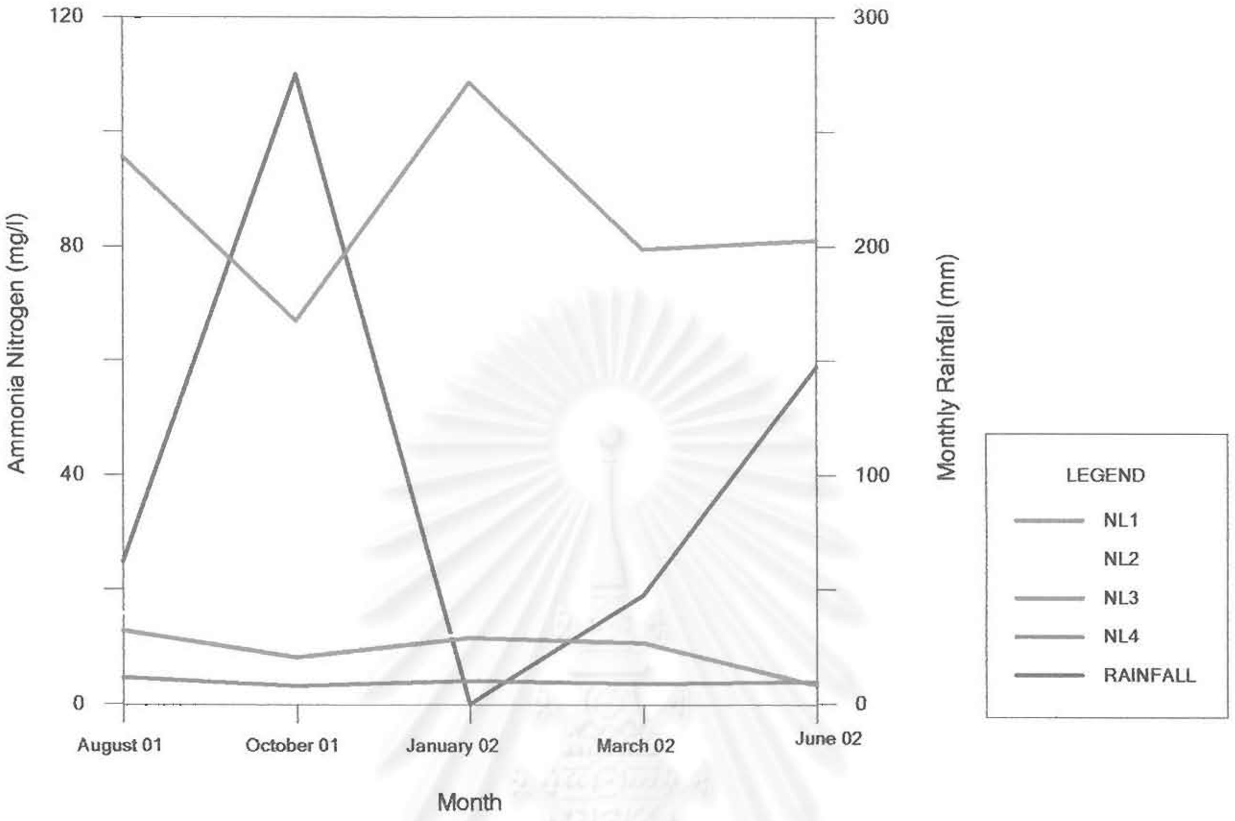
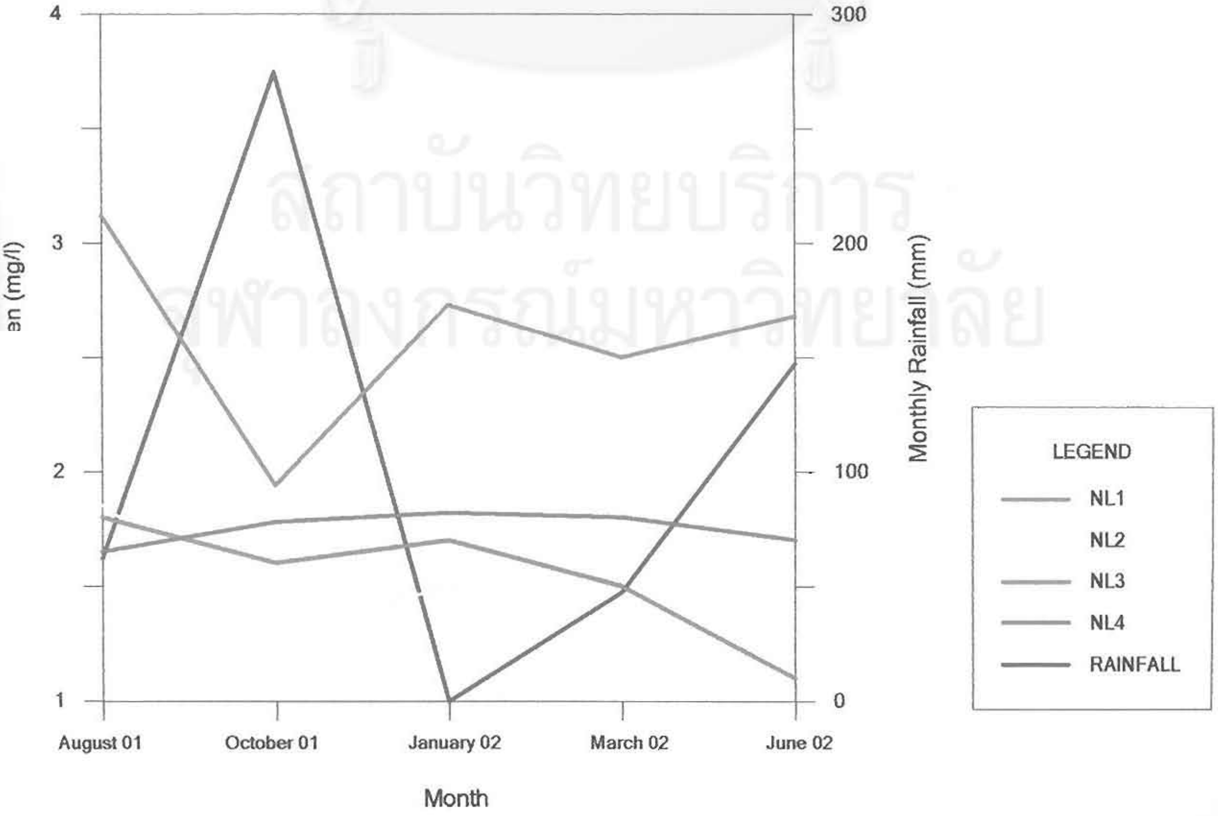
จุฬาลงกรณ์มหาวิทยาลัย

Appendix IV.7 Relation between Ammonia Nitrogen and Rainfall



Appendix IV.8 Relation between Nitrate Nitrogen and Rainfall



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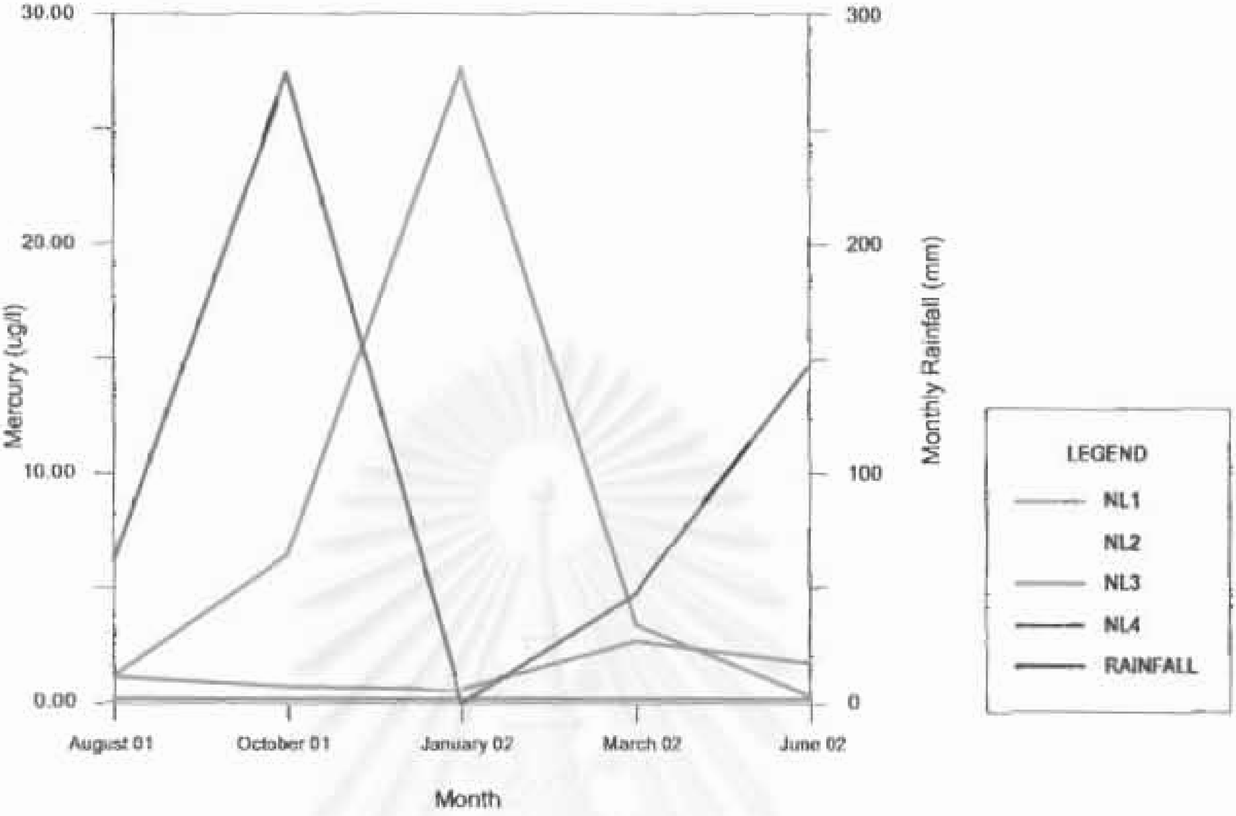
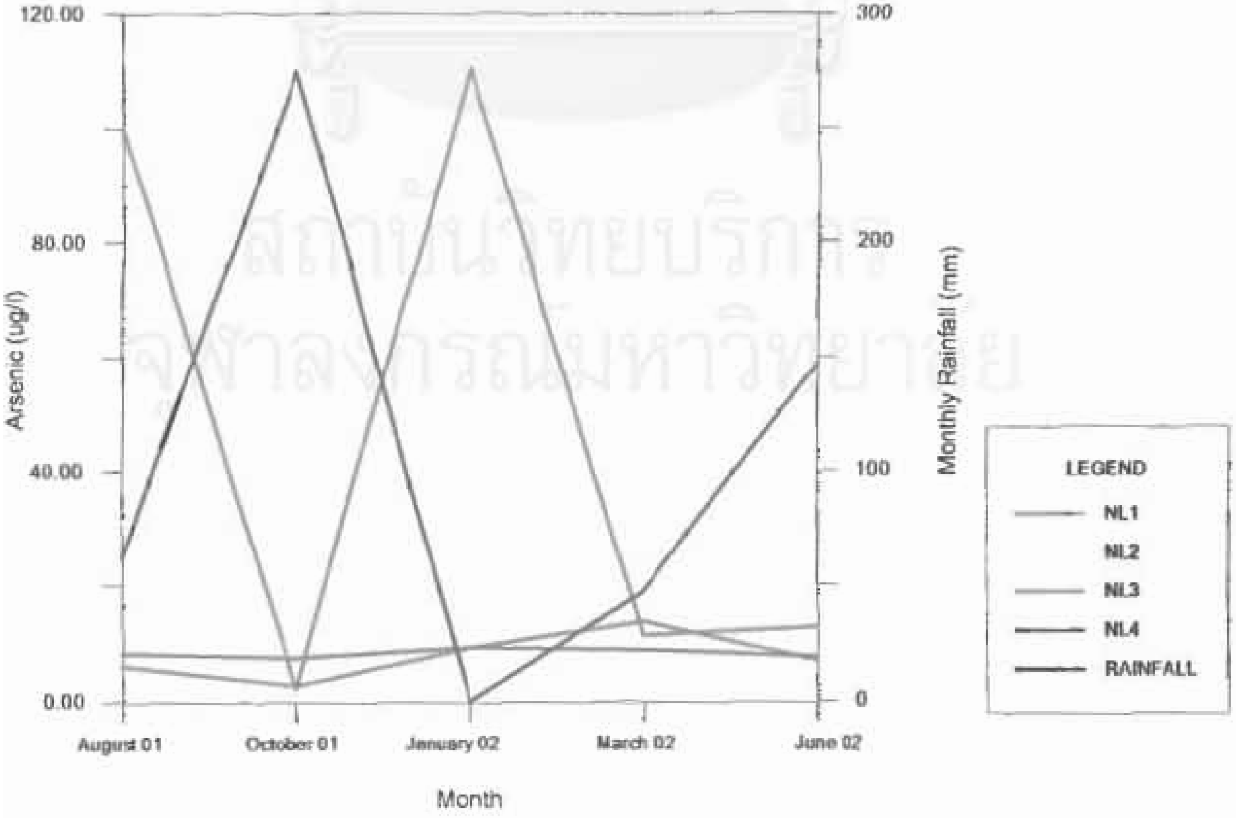
Appendix IV.9 Relation between Mercury and Rainfall



Appendix IV.10 Relation between Arsenic and Rainfall



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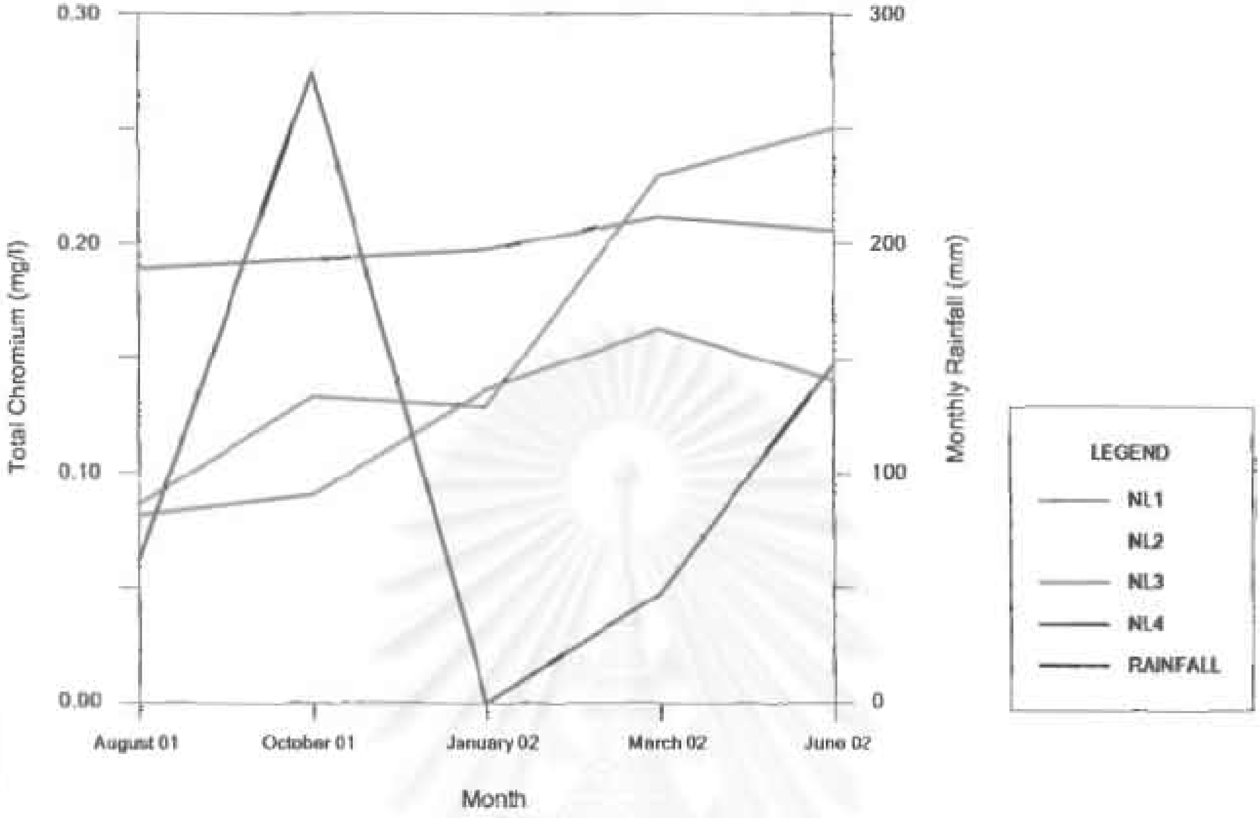
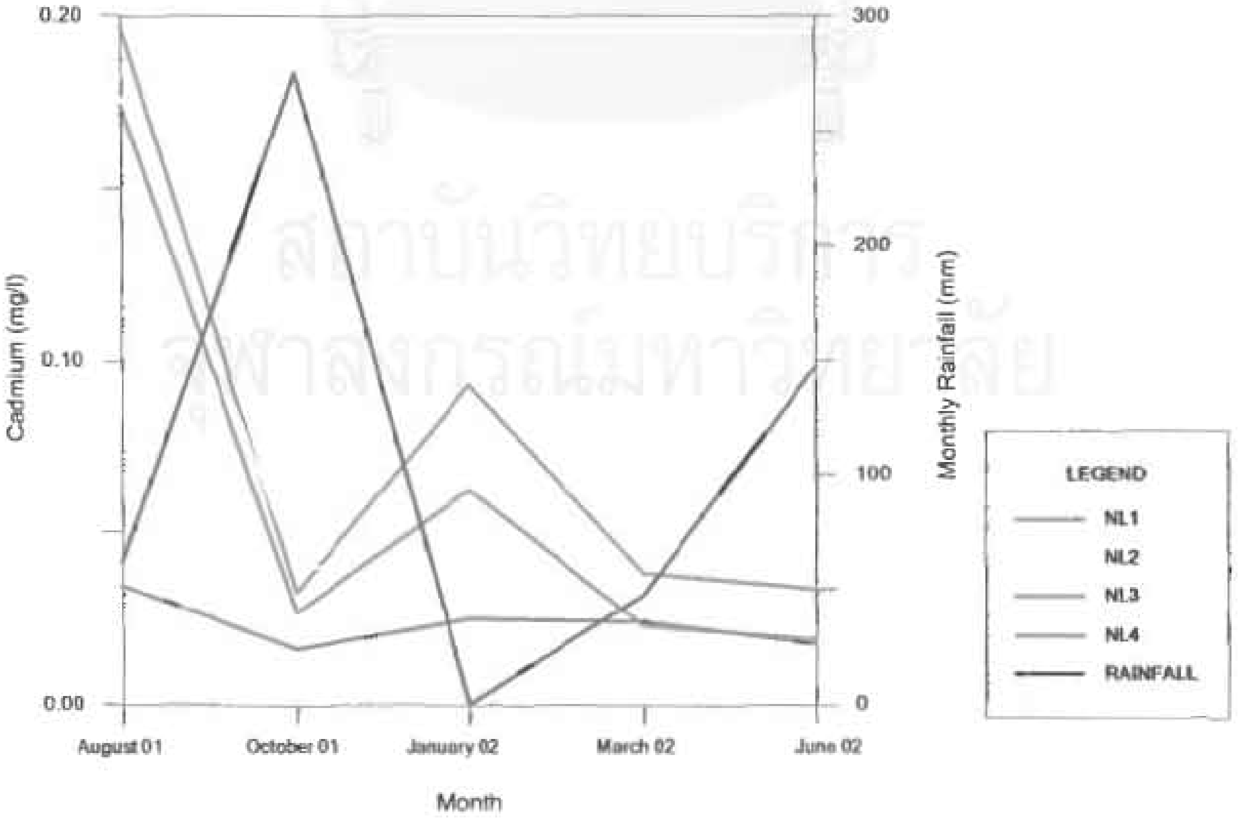
Appendix IV.11 Relation between Total Chromium and Rainfall



Appendix IV.12 Relation between Cadmium and Rainfall



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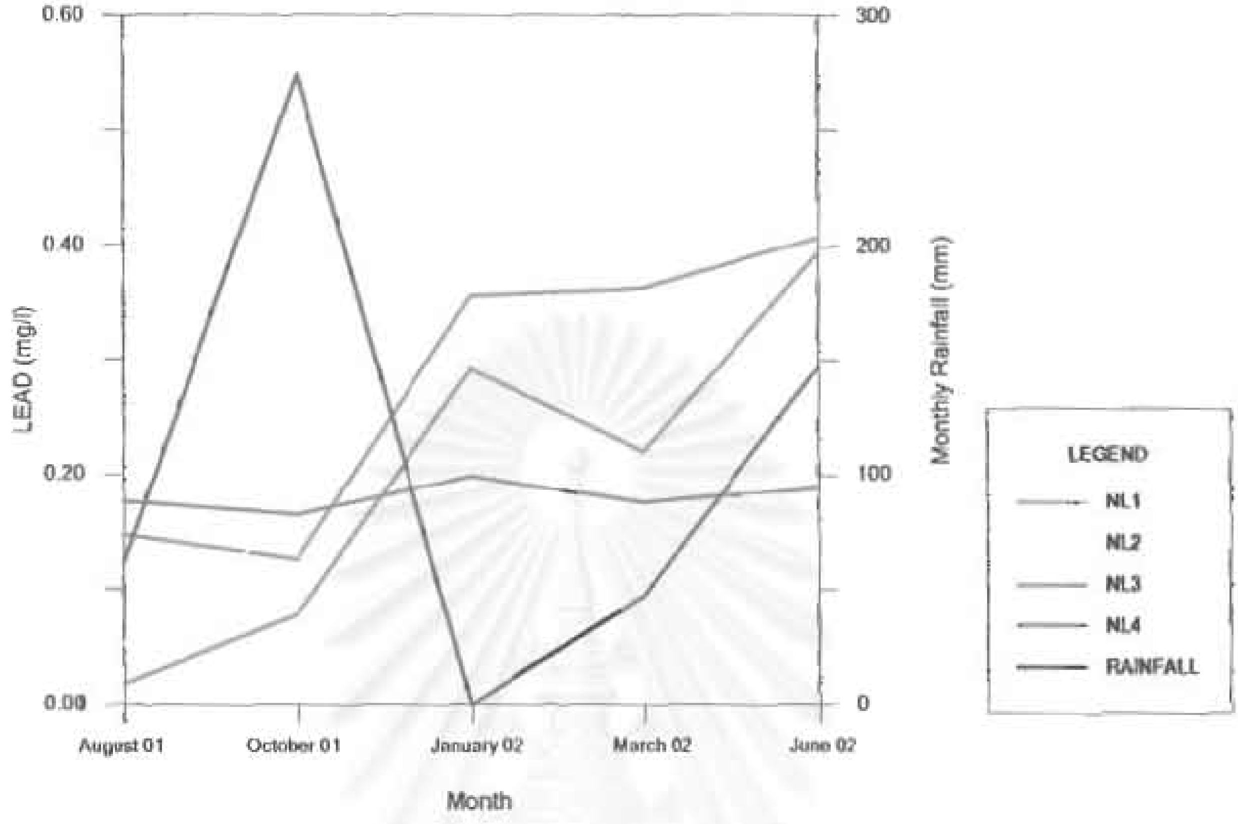
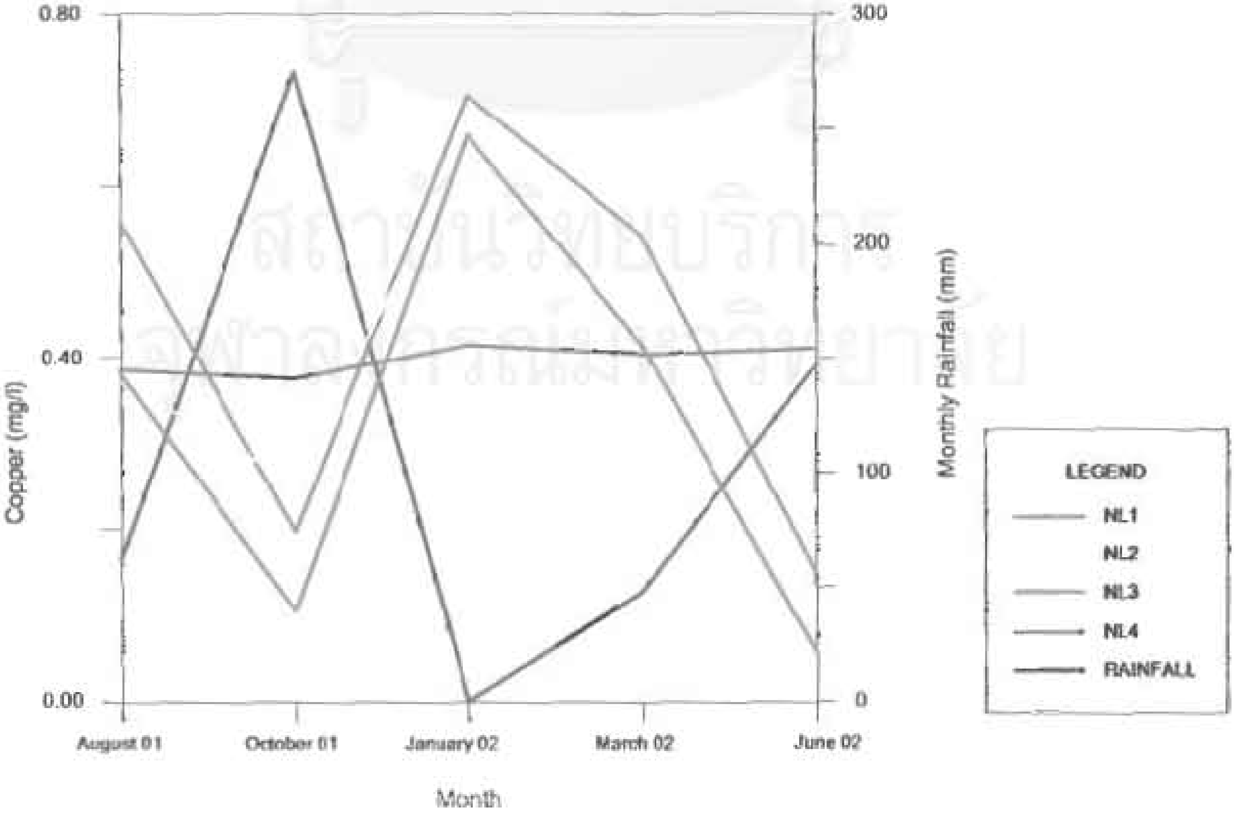
Appendix IV.13 Relation between Lead and Rainfall



Appendix IV.14 Relation between Copper and Rainfall



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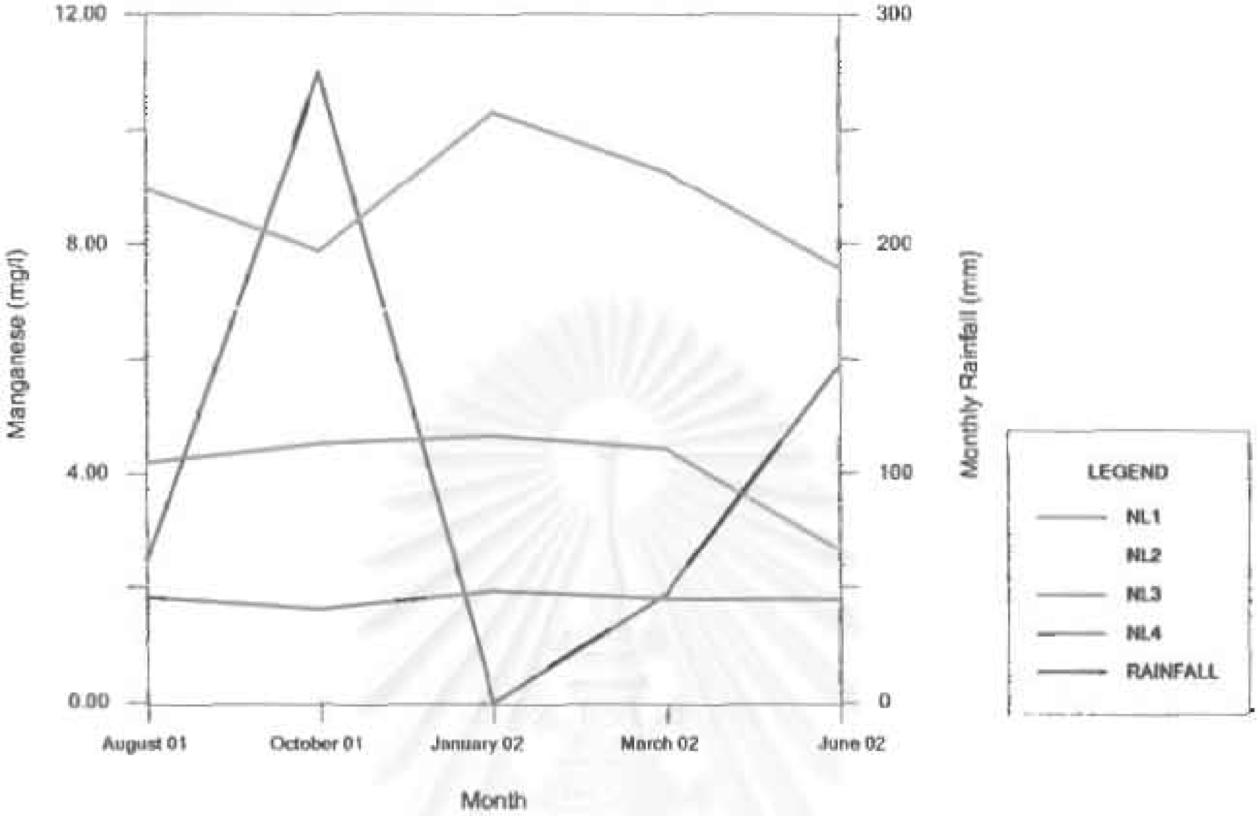
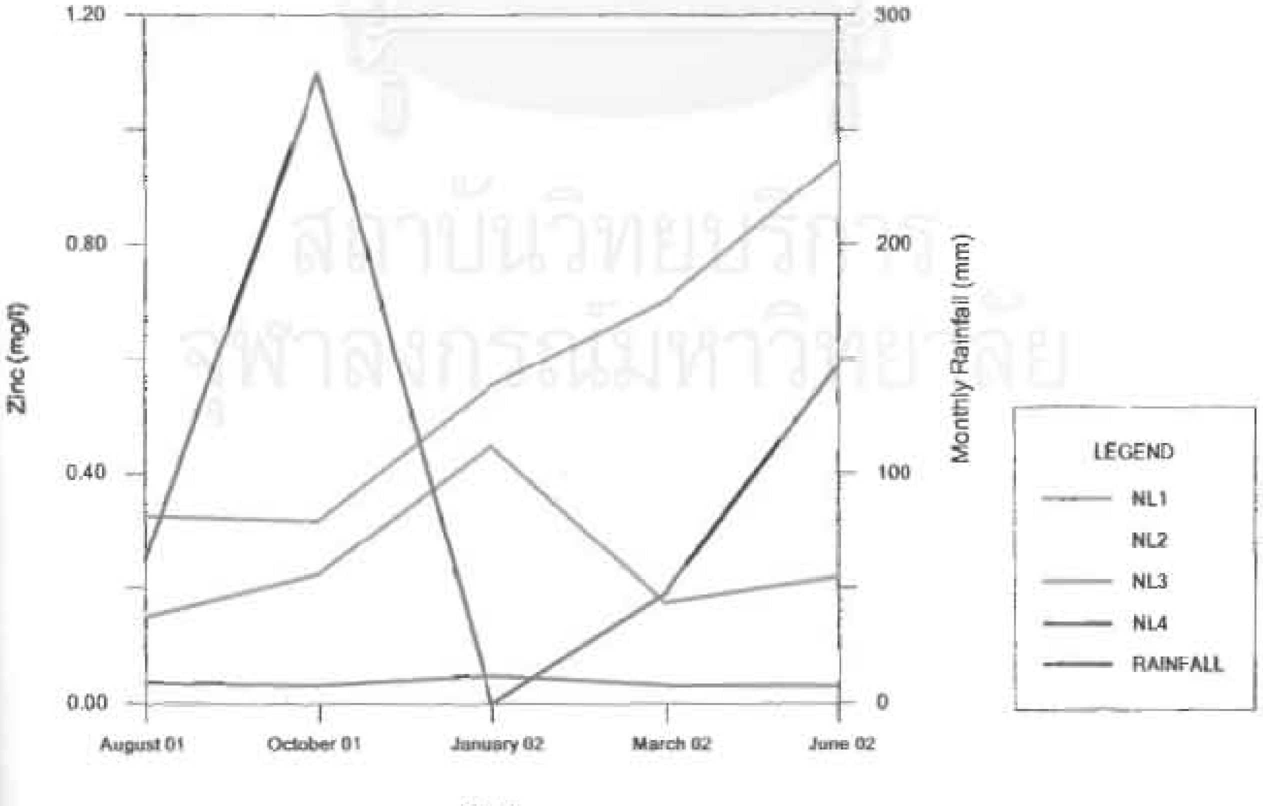
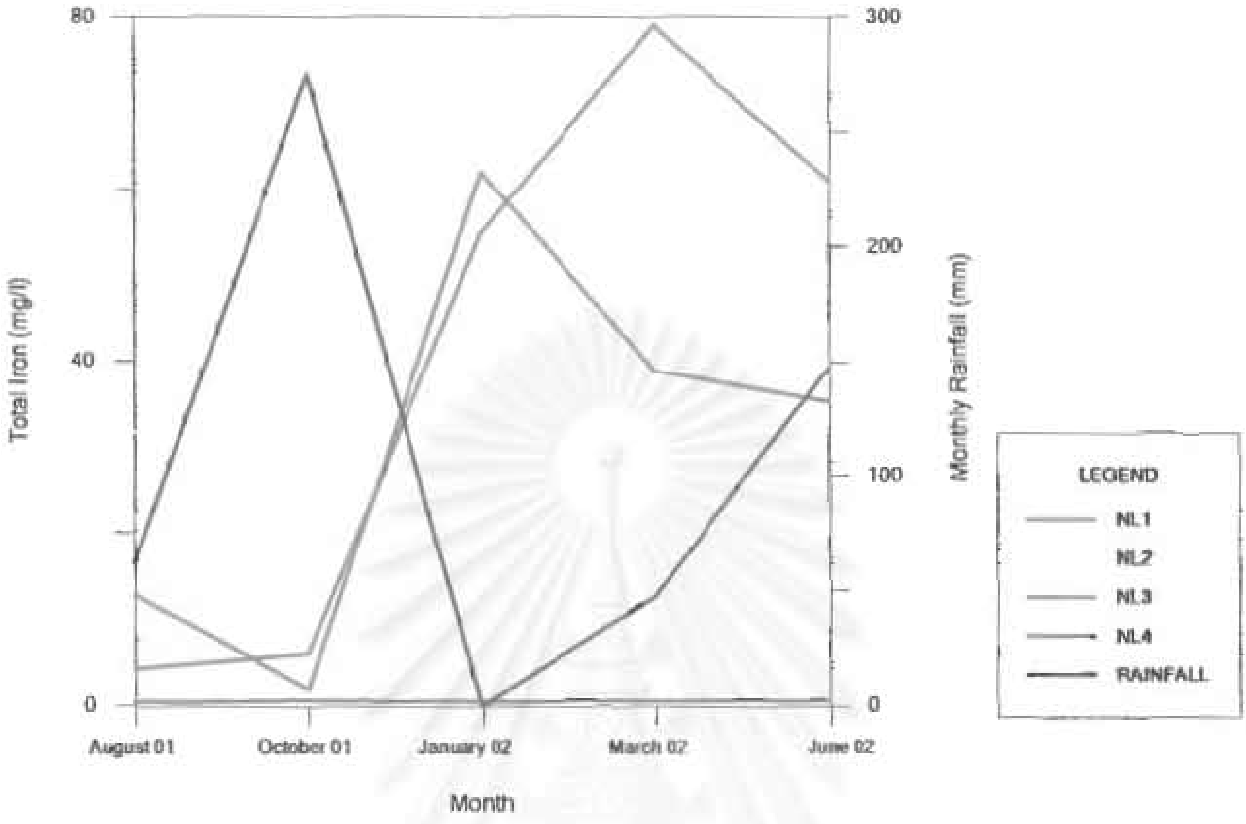
Appendix IV.15 Relation between Manganese and Rainfall



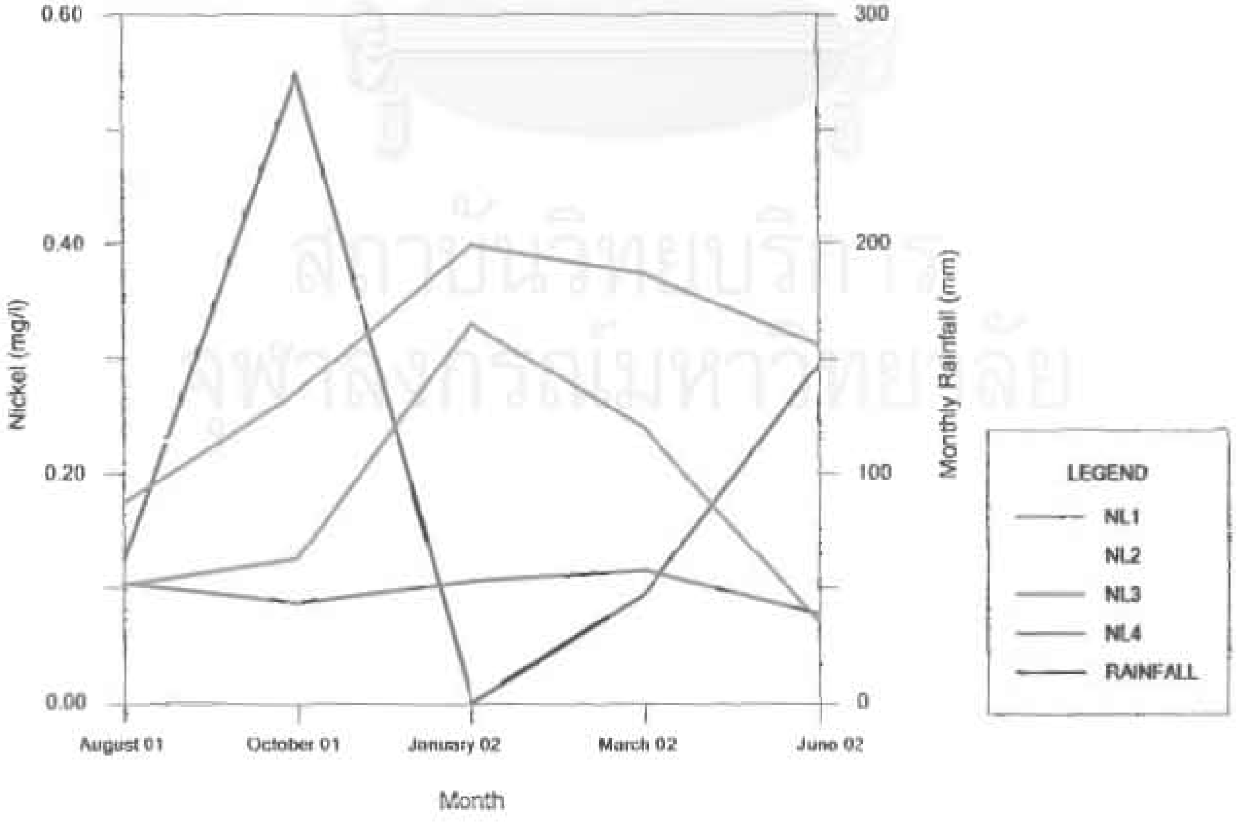
Appendix IV.16 Relation between Zinc and Rainfall



Appendix IV.17 Relation between Total Iron and Rainfall



Appendix IV.18 Relation between Nickel and Rainfall



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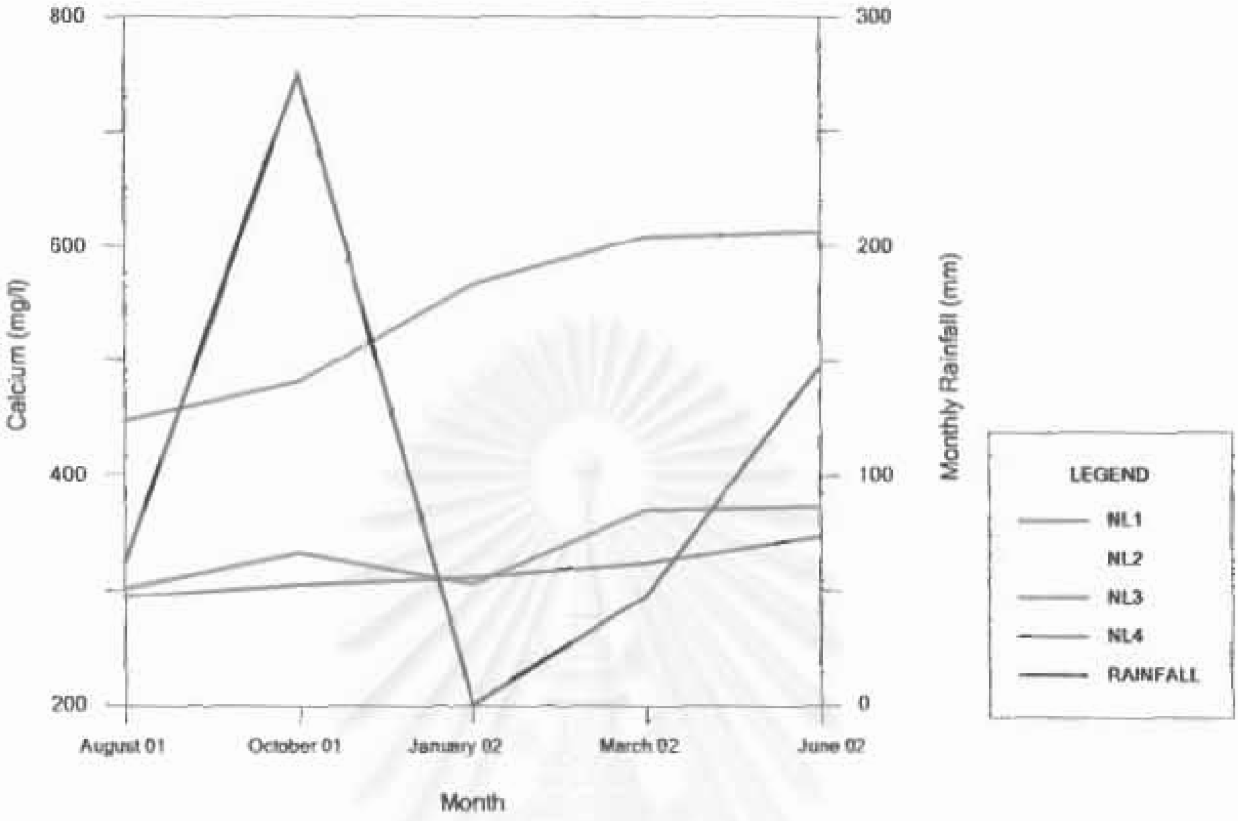
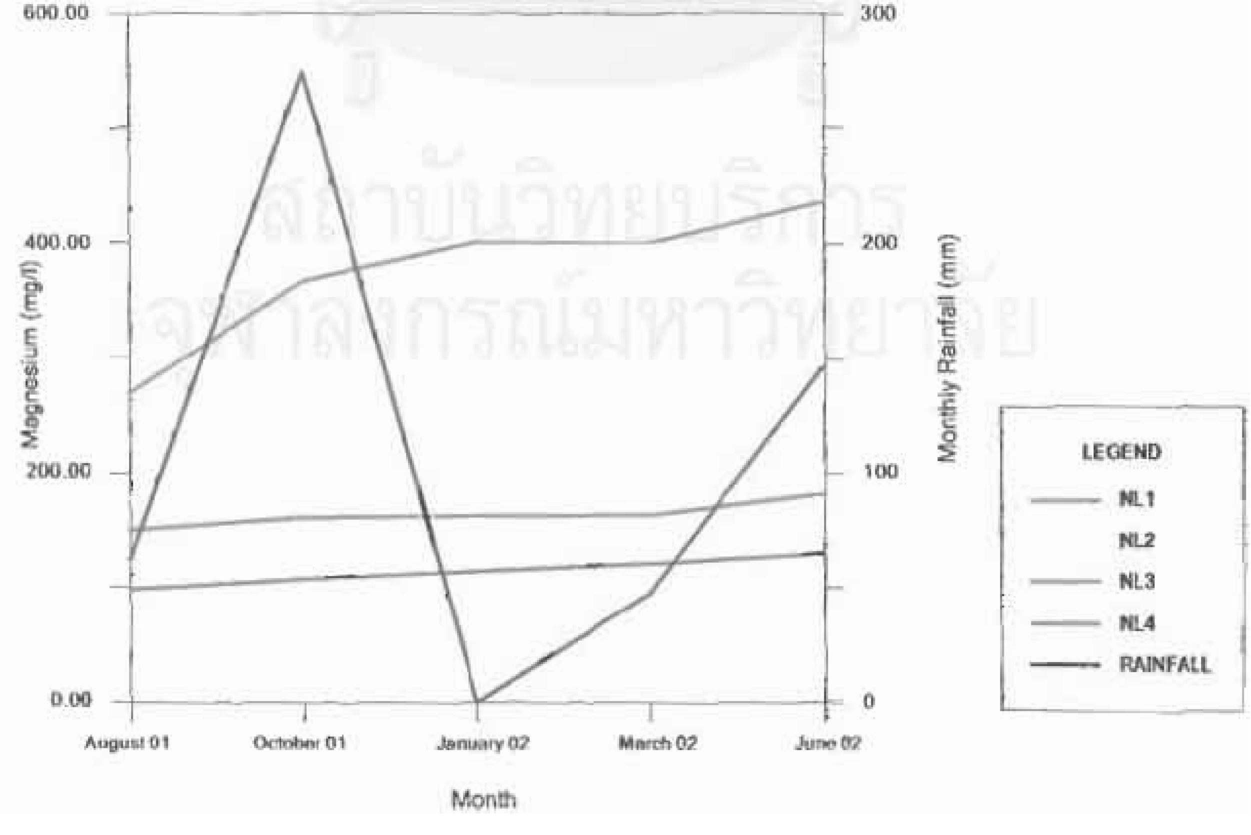


Appendix IV.20 Relation between Magnesium and Rainfall



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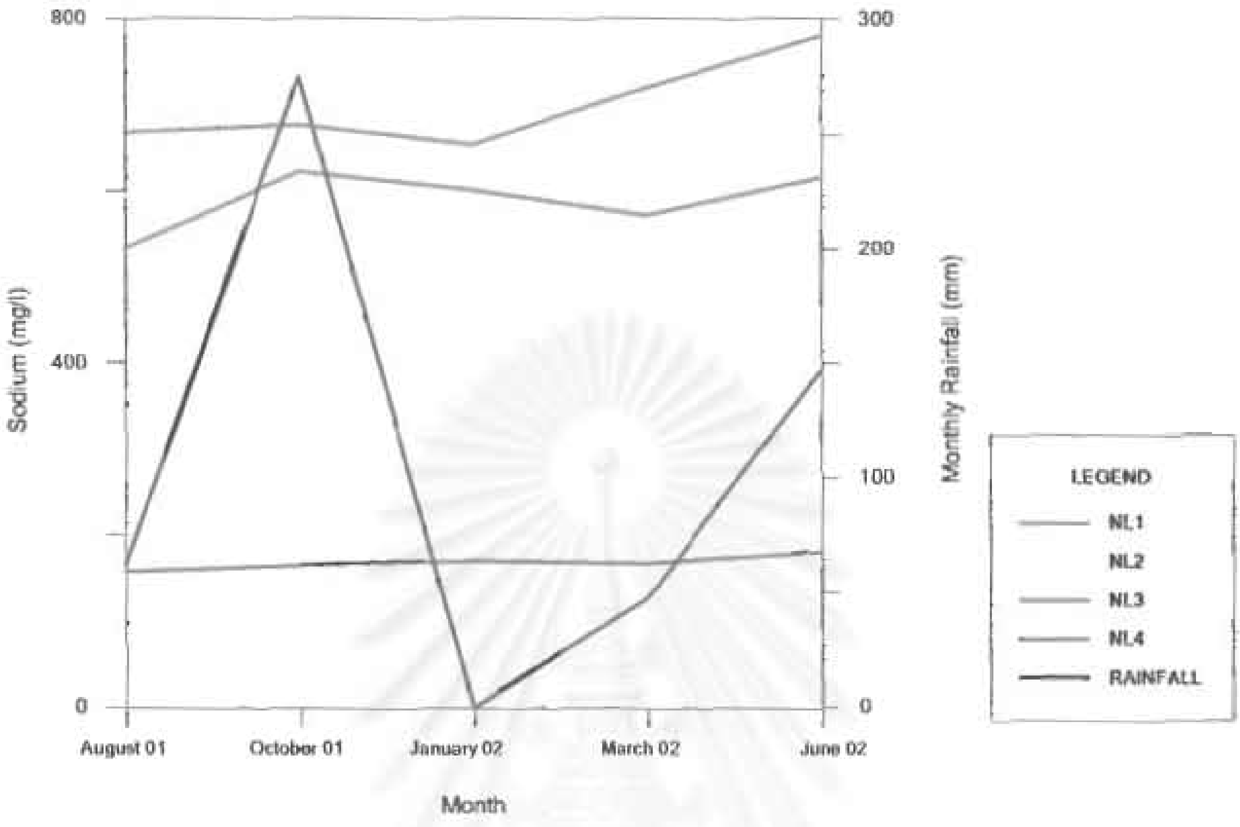
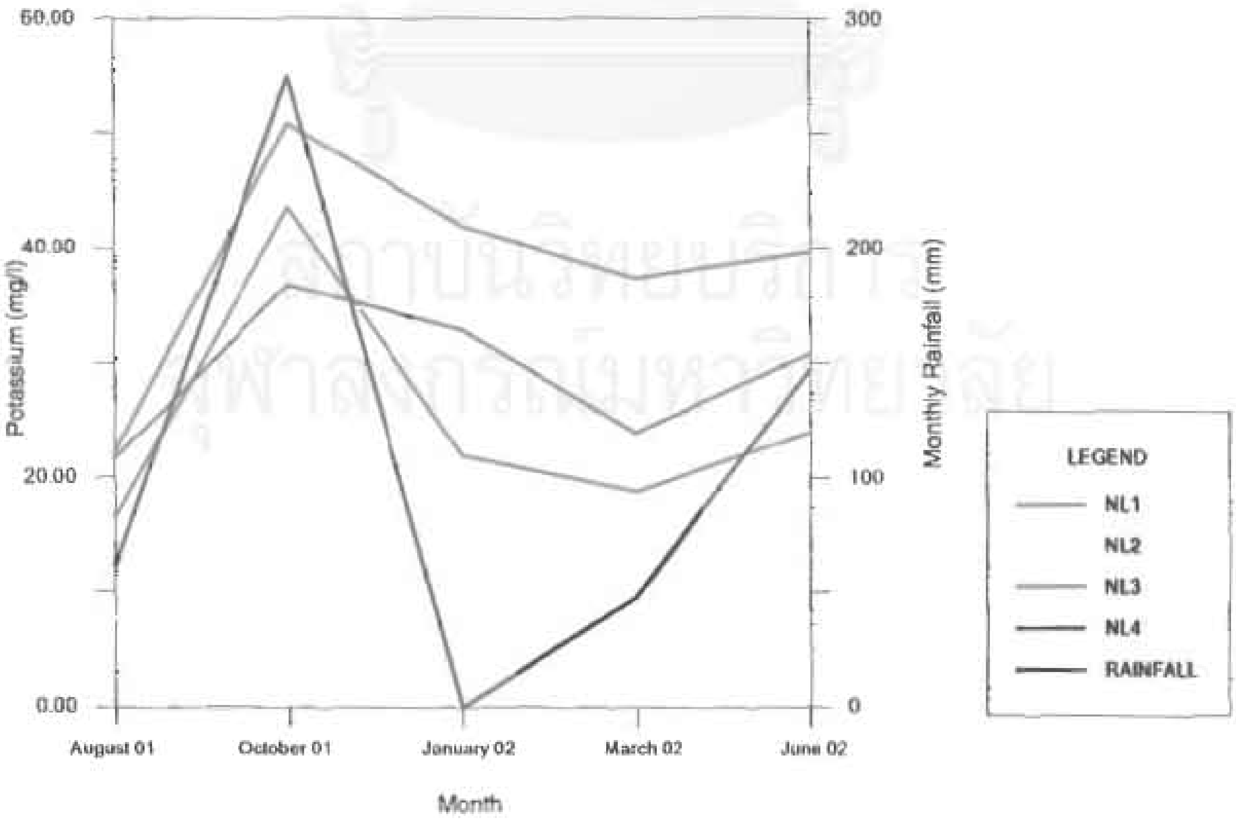
Appendix IV.21 Relation between Sodium and Rainfall



Appendix IV.22 Relation between Potassium and Rainfall



APPENDIX V

WATER QUALITY STANDARDS

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Table V.1 Drinking Water Quality Standards

Properties	**Parameters**	**Units**	**Standards values**	
			Max. acceptable conc.	**Max. allowable conc.**
1) Physical	Color	Pt-Co	5	15
	Taste*	-	non objectionable	non objectionable
	Odor*	-	non objectionable	non objectionable
	Turbidity	SSU	5	20
	pH	-	6.5-8.5	9.2
2) Chemical	Total Solids*	mg/dm^3	500	1,500
	Iron (Fe)	*mg/dm^3*	*0.5*	*1.0*
	Manganese (Mn)*	mg/dm^3	0.3	0.5
	Fe & Mn	mg/dm^3	0.5	1.0
	Copper (Cu)	mg/dm^3	1.0	1.5
	Zinc (Zn)	mg/dm^3	5.0	15.0
	Calcium (Ca)	mg/dm^3	75**	200
	Magnesium (Mg)	mg/dm^3	50	150
	Sulphate (SO_4)	mg/dm^3	200	250***
	Chloride (Cl)*	mg/dm^3	250	600
	Fluoride (F)	mg/dm^3	0.7	1.0
	Nitrate (NO_3)*	mg/dm^3	45	45
	Alkylbenzyl	mg/dm^3	0.5	1.0
	Sufonates (ABS)	mg/dm^3		
	Phenolicsubstance (as phenol)*	mg/dm^3	0.001	0.002
3) Toxic elements	Mercury (Hg)	mg/dm^3	0.001	-
	Lead (Pb)	mg/dm^3	0.05	-
	Arsenic (As)	mg/dm^3	0.05	-
	Selenium (Se)	mg/dm^3	0.01	-
	Chromium (Cr hexavalent)	mg/dm^3	0.05	-
	Cyanide (CN)	mg/dm^3	0.2	-
	Cadmium (Cd)	mg/dm^3	0.01	
	Barium (Ba)	mg/dm^3	1.0	
4) Bacterial	Standard Plate Count	colonies/cm^3	500	
	Total Coliform	MPN/100 cm^3	2.2	
	E Coli	MPN/100 cm^3	none	

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Remark : Pt-Co = Platinum Cobalt Scale

SSU = Silica Scale Unit

mg/dm^3 = milligram per cubic decimeter

MPN = Most Probable Number

* These value are allowed for tap water or ground water that is used temporary as drinking water. Such water with a parameter between the maximum acceptable concentration and the maximum allowable concentration can not be certified as standard drinking water for industrial products and stamped with the standard logo.

** If the calcium concentration is higher than the standard value and the magnesium concentration is lower than the standard value, calcium and magnesium will be identified in term of total hardness which standard value is less than 300 mg/dm^3 (as $CaCO_3$)

*** If the sulphate concentration of 250 mg/dm^3 is reached, the magnesium concentration must not be higher than 30 mg/dm^3

Source : Notification of the Ministry of Industry, No. 332, B.E. 2521 (1978), issued under the industrial Product Standards Act B.E. 2511 (1968), published in the Royal Government Gazette, Vol. 95, Part 68, dated July 4, B.E. 2521 (1978)

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Table V.2 Ground Water Quality Standards for Drinking Purposes

Properties	**Parameters**	**Units**	**Standards values**	
			Max. acceptable conc.	Max. allowable conc.
1) Physical	Color	Pt-Co	5	50
	Turbidity	JTU	5	20
	pH	-	7.0-8.5	6.5-9.2
2) Chemical	Iron (Fe)	mg/l	0.5	1.0
	Manganese (Mn)	mg/l	0.3	0.5
	Copper (Cu)	mg/l	1.0	1.5
	Zinc (Zn)	mg/l	5.0	15.0
	Sulphate (SO_4)	mg/l	200	250
	Chloride (Cl)	mg/l	200	600
	Fluoride (F)	mg/l	1.0	1.5
	Nitrate (NO_3)	mg/l	45	45
	Total Hardness as	mg/l	300	500
	$CaCO_3$	mg/l	200	250
	Non Carbonate Hardness			
	as $CaCO_3$	mg/l	750	1,500
3) Toxic elements	Total Solids	mg/l	none	0.05
	Arsenic (As)	mg/l	none	0.2
	Cyanide (CN)	mg/l	none	0.05
	Lead (Pb)	mg/l	none	0.001
	Mercury (Hg)	mg/l	none	0.01
	Cadmium (Cd)	mg/l	none	0.01
4) Bacterial	Selenium (Se)	colonies/ml	500	-
	Standard Plate Count	MPN/100 ml	2.2	-
	Total Coliform	MPN/100 ml	none	-
	E Coil			

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Remark : Pt-Co = Platinum Cobalt Scale

Source : Notification of the Ministry of Industry, No. 4, B.E. 2521 (1978), issued under the Ground water Act B.E. 2520 (1977), published in the Royal Government Gazette, Vol. 95, Part 66, dated June 27, B.E. 2521 (1978)

Table V.3 Groundwater Quality Standards

Parameter	Unit	Standard Value
1.Volatile Organic Compound		
1) Benzene	Milligram/litre	Not exceed 5
2) Carbon Tetrachloride	"	Not Exceed 5
3) 1, 2 – Dichloroethane	"	Not Exceed 5
4) 1,1-Dichloroethylene	"	Not exceed 7
5) cis-1,2-Dichloroethylene	"	Not exceed 70
6) trans-1,2-Dichloroethylene	"	Not exceed 100
7) Dichloromethane	"	Not exceed 5
8) Ethylbenzene	"	Not exceed 700
9) Styene	"	Not exceed 100
10) Tetrachoroetylene	"	Not exceed 5
11) Toluene	"	Not exceed 1,000
12) Trichloroethylene	"	Not exceed 5
13) 1,1,1-Trichloroethane	"	Not exceed 200
14) 1,1,2-Trichloroethane	"	Not exceed 5
15) Total Xylenes	"	Not exceed 10,000
2. Heavy metals		
1) Cadmium	Milligram/litre	Not exceed 0.003
2) Hexavalent Chromium	"	Not exceed 0.05
3) Copper	"	Not exceed 1
4) Lead	"	Not exceed 0.01
5) Manganese	"	Not exceed 0.5
6) Nickel	"	Not exceed 0.02
7) Zinc	"	Not exceed 5
8) Arsenic	"	Not exceed 0.01
9) Selenium	"	Not exceed 0.01
10) Mercury	"	Not exceed 0.001
3. Pesticides		
1) Chlordane		
2) Dieldrin	"	Not exceed 0.03
3) Heptachlor	"	Not exceed 0.4
4) Heptachlor Epoxide	"	Not exceed 0.2
5) DDT	"	Not exceed 2.0
6) 2, 4 - D	"	Not exceed 30
7) Atrazine	"	Not exceed 3.0
8) Lindane	"	Not exceed 0.2
9) Pentachlorophenol	"	Not exceed 1

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Table V.3 Groundwater Quality Standards (Cont.)

Parameter	Unit	Standard Value
4. Others		
1) Benzo (a) pyrene	Microgram/litre	Not exceed 0.2
2) Cyanide	"	Not exceed 200
3) PCBs	"	Not exceed 0.5
4) Vinyl Chloride	"	Not exceed 2

Remark : 1. Standard Methods for the Examination of Water and Wastewater which American Public Health Association, American Water Works Association and the U.S.A. Water Environment Federation or Manual for Water and Wastewater Analysis of Thailand Environmental Engineering Association accept.

2. Methods for Sampling and Preservation follow as PCD Announcement in the Royal Government Gazette

Source : Notification of the National Environmental Board No. 20, B.E. 2543 (2000), issued under the Enhancement & Conservation of National Environment Quality Act B.E. 2535 (1992), published in the Royal Government Gazette, Vol. 117 Special part 95 D, dated September 15 , B.E. 2543 (2000)

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Table V.4 Surface Water Quality Standards : Classification and Objectives

Parameters	Units	Statistic	Standards Values for Class***				
			1	2	3	4	5
1. Color, Odor and Taste	-	-	n	n	n	n	-
2. Temperature	°C	-	n	n'	n'	n'	-
3. pH Value	-	-	n	5-9	5-9	5-9	-
4. Dissolved Oxygen	mg/l	P20	n	6	4	2	-
5. BOD (5 day, 20° C)	mg/l	P80	n	1.5	2.0	4.0	-
6. Coliform Bacteria							
- Total Coliform	MPN/100 ml	P80	n	5,000	20,000	-	-
- Fecal Coliform	MPN/100 ml	P80	n	1,000	4,000	-	-
7. NO_3-N	mg/l	Max. allowance	n	5.0	5.0	5.0	-
8. NH_3-N	mg/l	Max. allowance	n	0.5	0.5	0.5	-
9. Phenols	mg/l	Max. allowance	n	0.005	0.005	0.005	-
10. Copper (Cu)	mg/l	Max. allowance	n	0.1	0.1	0.1	-
11. Nickel (Ni)	mg/l	Max. allowance	n	0.1	0.1	0.1	-
12. Manganese (Mn)	mg/l	Max. allowance	n	1.0	1.0	1.0	-
13. Zinc (Zn)	mg/l	Max. allowance	n	1.0	1.0	1.0	-
14. Cadmium (Cd)	mg/l	Max. allowance	n	0.005*	0.005*	0.005*	-
15. Chromium (Cr hexavalent)	mg/l	Max. allowance	n	0.05	0.05	0.05	-
16. Lead (Pb)	mg/l	Max. allowance	n	0.05	0.05	0.05	-
17. Total Mercury (Hg)	mg/l	Max. allowance	n	0.002	0.002	0.002	-
18. Arsenic (As)	mg/l	Max. allowance	n	0.01	0.01	0.01	-
19. Cyanide (CN)	mg/l	Max. allowance	n	0.005	0.005	0.005	-
20. Radioactivity							
- Gross alpha	Becqurel/l	Max. allowance	n	0.1	0.1	0.1	-
- Gross beta	Becqurel/l	Max. allowance	n	1.0	1.0	1.0	-
21 Organochlorine Pesticides (total)	mg/l	Max. allowance	n	0.05	0.05	0.05	-
22. DDT	µg/l	Max. allowance	n	1.0	1.0	1.0	-
23. α BHC	µg/l	Max. allowance	n	0.02	0.02	0.02	-
24.Dieldrin	µg/l	Max. allowance	n	0.1	0.1	0.1	-
25. Aldrin	µg/l	Max. allowance	n	0.1	0.1	0.1	-
26. Heptachlor & Heptachlor epoxide	µg/l	Max. allowance	n	0.2	0.2	0.2	-
27. Endrin	µg/l	Max. allowance	n	none	none	none	-
	µg/l						

Note : P = Percentile value

n = naturally

n' = naturally but changing not more than 3 °C

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* = When water hardness not more than 100 mg/l as $CaCO_3$

** = When water hardness more than 100 mg/l as $CaCO_3$

*** = Water Classification

Classifications	Objectives/Condition & Beneficial Usage
Class 1	Extra clean fresh surface water resources used for : (1) conservation not necessary pass through water treatment processes require only ordinary process for pathogenic destruction (2) ecosystem conservation where basic organisms can breed naturally
Class 2	Very clean fresh surface water resources used for : (1) consumption which requires ordinary water treatment processes before use (2) aquatic organism of conservation (3) fisheries (4) recreation
Class 3	Medium clean fresh surface water resources used for : (1) consumption, but passing through an ordinary treatment processes before using (2) agriculture
Class 4	Fairly clean fresh surface water resources used for : (1) consumption, but requires special water treatment processes before using (2) Industry
Class 5	The resources which are not classification in class 1-4 and used for navigation

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Source : Notification of the National Environmental Board, No. 8, B.E. 2537, issued under the Enhancement and Conservation of National Environment Quality Act B.E. 2537, published in the Royal Government Gazette, Vol. 111, Part 16, dated February 24, B.E. 2537 (1994).

APPENDIX VI

PHOTOS

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Appendix VI-1 Paddy field around disposal site in rainy season

Appendix VI-2 Paddy field around disposal site in winter season

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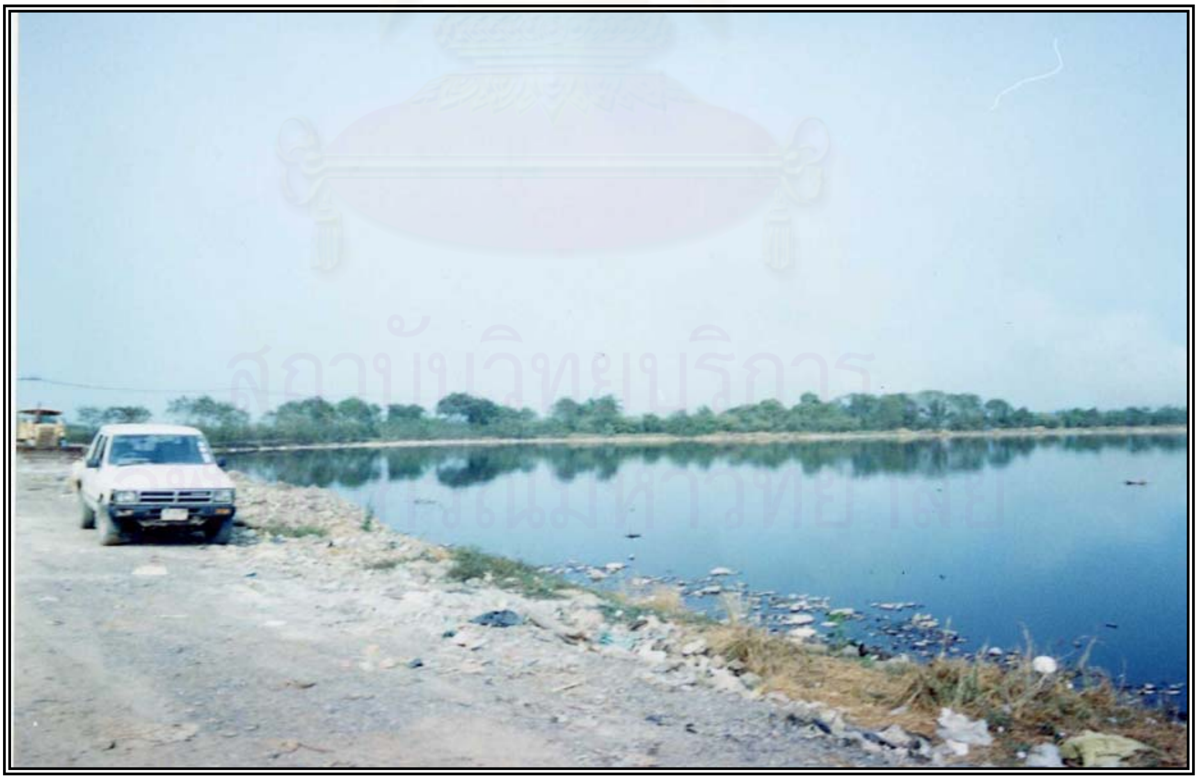
Appendix VI-3 Leachate collection land



Appendix VI-4 Leachate collection land

Appendix VI-5 Incineration facility for infectious waste

Appendix VI-6 Ground improvement

Appendix VI-7 After ground improvement

Appendix VI-8 Location of NL3

Appendix VI-9 New road completed in 2002 lying between dump site and leachate location land

Appendix VI-10 Dike built around paddy field to contain water.

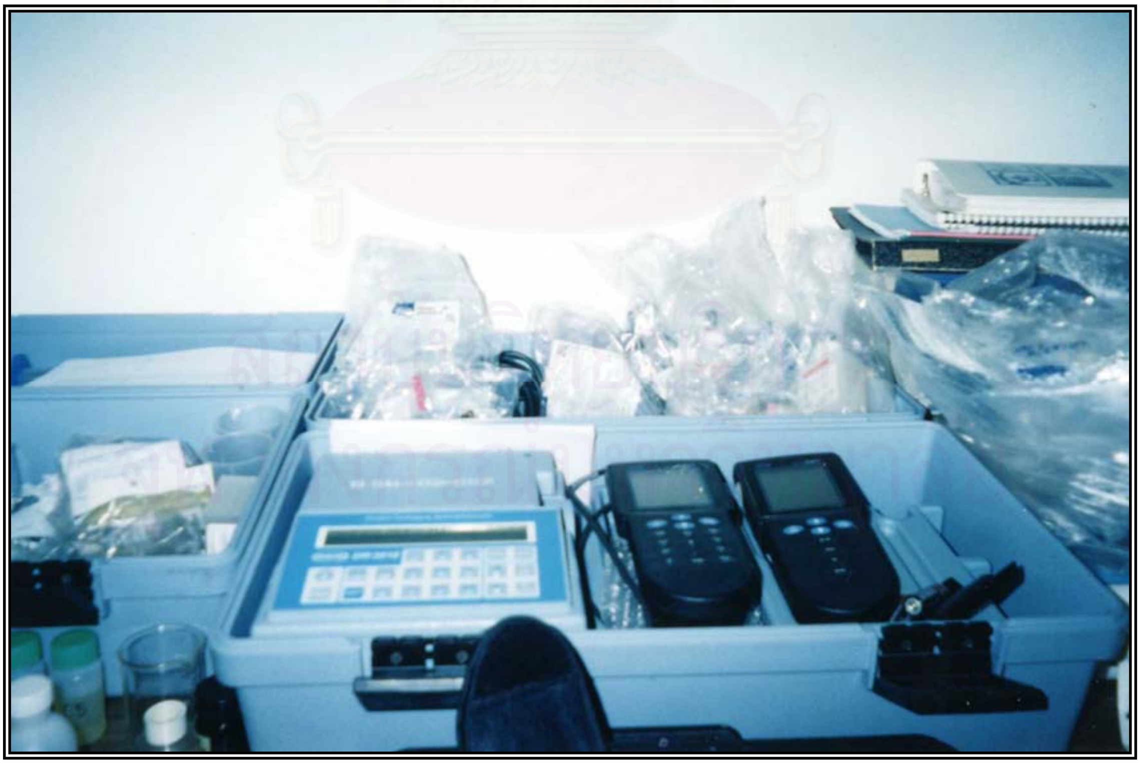
Appendix VI-11 Khlong Hai Roi is located the east of disposal site

Appendix VI-12 Khlong Na Mon is located the west of disposal site

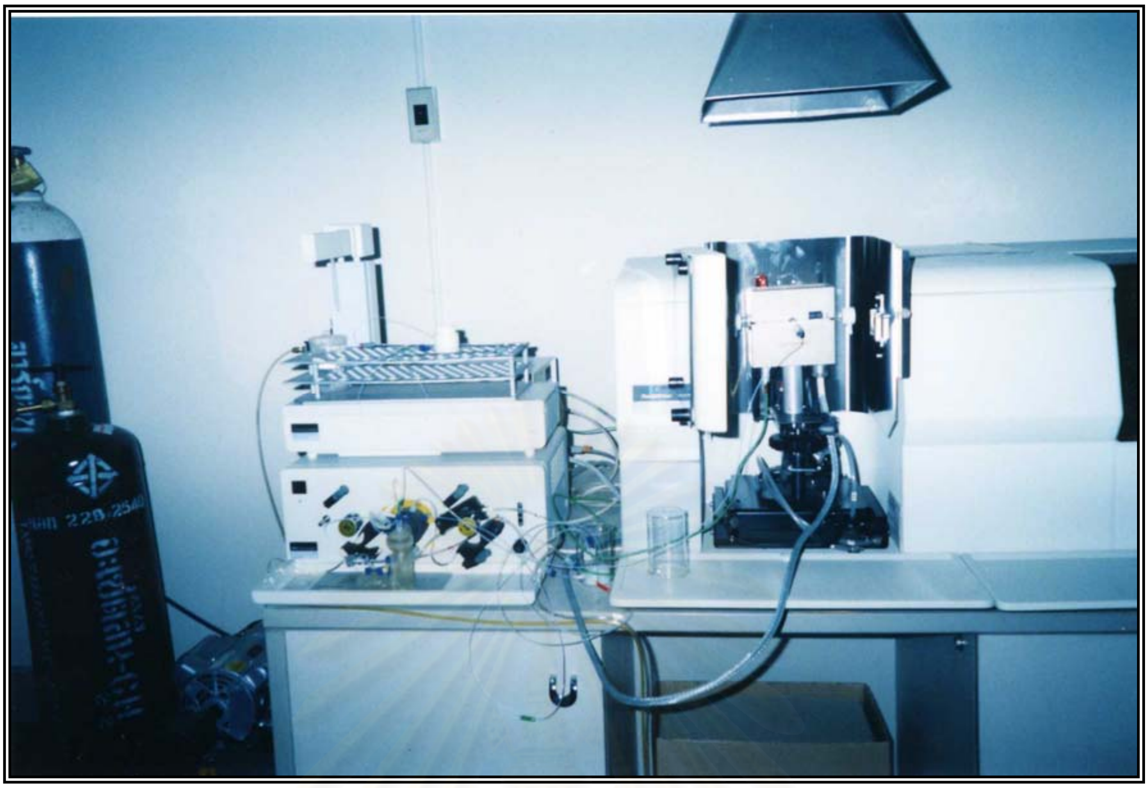
Appendix VI-13 Pond is located the north of disposal site

Appendix VI-14 Water collection from the monitoring well

Appendix VI-15 Field measurement



Appendix VI-16 Advanced Water Quality Laboratory, DREL/2010



Appendix VI-17 Atomic Absorption Spectrometer, PerkinElmer, AA300
and FIAS 400

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BIOGRAPHY

Miss Naiyana Naimolee was born in Amphoe Muang, Changwat Lopburi , on January 6, 1976. She received the degree of B.Sc. in Geotechnology from the Department of Geotechnology, Faculty of Technology, KhonKaen University, 1997. After graduation, she worked at Layne (Thailand) Ltd.

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